NAVAL RESEARCH

REVIEWS

FEBRUARY - MARCH
1966

20th Year on the Frontier of Science

The Shock Tube and Plasma Dynamics

Vicennial Article

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Fifteen years ago, studies of high-temperature gas dynamics were confined largely to basic research being conducted at a few universities. Today, this fundamental research—much of it supported by the Office of Naval Research—has paid handsome dividends in a broad range of applications for national defense, space exploration, and industrial technology.

These advances in knowledge were facilitated greatly by the development of the shock tube as an experimental tool for studying gases at elevated temperatures.* Much of the basic work in shock-tube development was sponsored by ONR in the late 1940's and early 1950's. Without this support of fundamental research, the advances in knowledge to be discussed in this paper would be far from their present stage of utility. The ONR policy of supporting research, without tying such investigations to an immediately apparent application, has allowed researchers to explore new fields and discover concepts and resources that would never have been tapped by "mission oriented" studies. Development of the shock tube is a good example of the fruits of this policy.

Although it had been shown by Vieille in 1899 that waves moving faster than the speed of sound could be created easily in straight tubes by bursting a diaphragm separating regions of high- and low-pressure gases, the shock tube did not come into serious use until about 1946 when Payman and Shapard, in England, used this instrument to study the aerodynamics of shock waves. In the late 1940's, shock tubes received considerable development as instruments for the study of aerodynamics and diffraction effects of shock waves and as economical substitutes for transonic and supersonic wind tunnels. In the work of Bleakney and his associates (1949), the shock tube was refined to a precision instrument for aerodynamic research.

The adaptation of the shock tube to the production of high-temperature gases for gas-dynamics studies began early in the 1950's at the laboratories of Laporte at the University of Michigan and at Cornell University by the author. Both of these programs were supported by ONR.

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*Kantrowitz, Arthur, "Shock Tubes for High Temperature Gas Kinetics," Avco-Everett Res. Lab. Res. Rept., October 1962.

The shock tube is basically a very simple device. It consists of a tube divided by a diaphragm into two sections – a high-pressure (driver) section and a low-pressure (test) section. The test section is filled with the gas of interest for the experiment. The pressure in the driver section is increased until the diaphragm is ruptured. The sudden intrusion of driver gas into the low-pressure section causes a compression wave that steepens quickly into a shock wave. The shock wave moves through the test gas ahead of the expanding driver gas.

Thus, between the shock front and the interface with the driver gas is a sample of test gas that has been heated suddenly by the passage of the shock. This homogeneous gas sample (HGS) is chemically clean and has an enthalpy and pressure that can be calculated precisely from knowledge of the undisturbed test-gas conditions, the measured shock velocity, and the laws of conservation of mass, momentum, and energy.

The gross characteristics of the HGS, then, can be defined and controlled closely, allowing detailed study to be made of the chemical kinetics, radiation, heat transfer, ionization, and other specific characteristics of the gas sample. No other experimental tool is capable of producing, with such simplicity and flexibility, gas samples that are as well-defined, high in temperature, and free of chemical impurities.

In the earliest shock-tube experiments, the driver-gas pressure was increased by pumping until the diaphragm burst. By means of hydrogen drivers, temperatures were produced in argon, for example, of up to 12,000°K at shock speeds of 3.0 millimeters per microsecond. Later, combustible mixtures were used as drivers. By the early 1960's, drivers employing electric-arc heating of the driving gas were developed. Typical operating conditions for pressure-driven, combustion-driven, and arc-driven shock tubes are shown in Figure 1. Figures 2 and 3 show combustion driven and arc-driven shock tubes.

In the mid-1950's, the Nation embarked on the truly momentous technological program of developing intercontinental ballistic missiles. One of the many unsolved questions facing the ICBM program was the so-called "reentry problem": how to design a reentry vehicle that could survive the heating associated with its terminal flight through the atmosphere.

Here, the high-temperature shock tube became an indispensable tool for applied research. The environment of reentry was essentially new to both scientists and engineers. Bodies flying at velocities of 20,000 feet per second or more created shock waves that heated the air to incandescence, dissociated the oxygen and nitrogen molecules, and even ionized a considerable fraction of the air. Determining this environment quantitatively, so that meaningful design information could be produced, required a combination of hypersonic aerodynamics and gas physics.

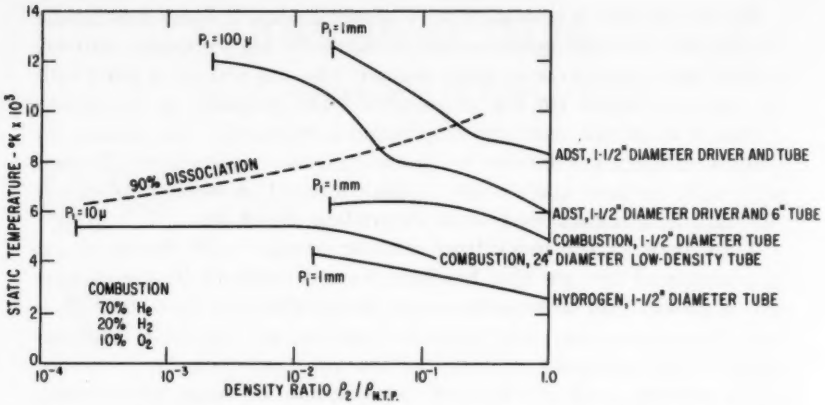
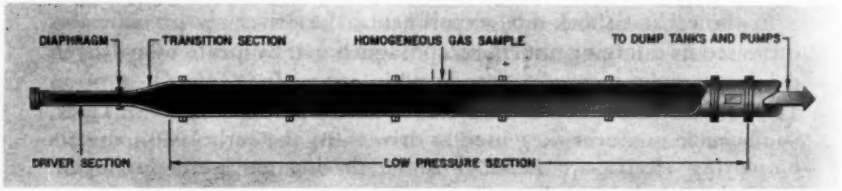


Figure 1 – Temperatures and densities (after equilibration) obtainable in air behind the incident shock for various types of diaphragm shock-tube drivers. The driver pressure is limited to 10,000 pounds per square inch for the ADST (arc driven shock tubes) and the combustion drivers and to 2000 psi for the hydrogen driver. The dotted line marked "90% Dissociation" denotes region above which 90 percent of gas molecules are dissociated into atoms.



DIMENSIONS

	Length (feet)	*Inner Diameter (inches)*
Driver Section	6	5
Transition Section	4	
Low-pressure Section	42	24

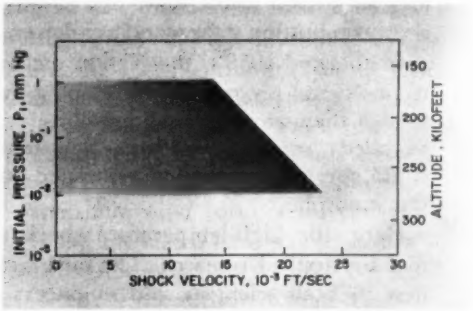
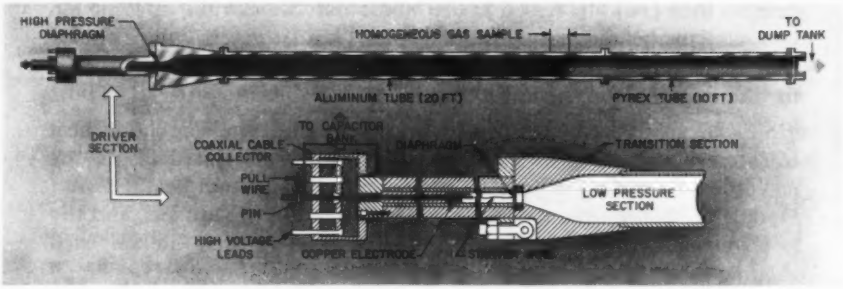


Figure 2 – Schematic of a 24-inch interior-diameter combustion-driven shock tube. High pressure in the driver section bursts the diaphragm, causing a shock wave to traverse the low-pressure test section. Immediately behind the shock wave is the homogeneous gas sample. The graph shows shock velocities and gas pressures attainable in this device. Altitude in thousands of feet is equivalent to initial pressure of the shocked gas and is given to relate behavior of gases in the shock tube to that of solid bodies entering the atmosphere at high speeds.



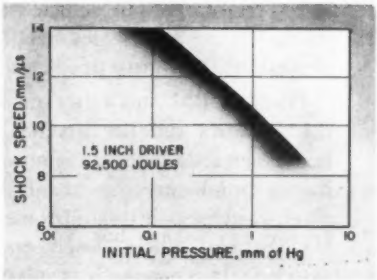


Figure 3 – Schematic of electric arc-driven shock tube including close-up view of driver section. The graph shows heat-transfer measurements made in this apparatus.

Shock tubes were used to answer the key questions of hypersonic reentry and flight.* These questions concerned the following factors:

- The chemical kinetics of air and its component gases at temperatures of several thousand degrees Kelvin.
- The aerodynamic heat transfer to the reentry body through both laminar and turbulent boundary layers.
- The radiative heat transfer, which necessitated studies of the radiative emission from high-temperature gases.
- The effects of gas ionization on the electrical conductivity of air and, hence, on the ability to communicate with the vehicle during reentry (the "plasma sheath" radio-blackout effect).

By means of shock tubes, it was possible to determine the reentry environment with sufficient precision so that successful reentry vehicles could be developed. Chemical kinetics, radiative emission from hot gases, and ionization studies were conducted directly by means of shock-tube experiments. Heat-transfer tests were carried out both in shock tubes and in arc-jet "wind tunnels."

The development of electric-arc plasma generators made it possible to conduct "wind tunnel" tests of reentry vehicle models under conditions simulating closely those of flight. Reentry-vehicle materials and

*Rose, P. H., "Shock Tube Research in Hypersonic Aerodynamics," Avco-Everett Res. Lab. AMP 20, May 1958.

designs thus could be tested in the laboratory. Shock-tube information was vital to the successful use of arc-jet "wind tunnels," since shock-tube data were used to design the arcs and provided calibration data for the operation of the arcs.

Shock-tube experiments provided knowledge of the stagnation heat transfer rate under given reentry conditions. From this data, the arc jet could be adjusted to provide the necessary stagnation heat transfer. Models of ablating reentry vehicles were tested in the arc jets, and the rate of ablation was measured. Thus the heat-transfer rate for each ablating material was determined. This technique was verified brilliantly on April 8, 1959, on the first flight of an ablating reentry vehicle over an ICBM trajectory. The vehicle was recovered, and the amount of material ablated from it was measured. The actual flight data were within ten percent of the figure predicted from laboratory experiments.

While ICBM and other missile systems are now a standard part of the Nation's defense arsenal, laboratory studies of reentry still are being pressed. Research is now focused on the problems of discriminating a bomb-carrying reentry vehicle from decoys and—from the offensive viewpoint—on problems of designing decoys that will simulate the reentry vehicle closely enough to allow it to penetrate defensive systems. This research revolves around the "signatures" produced by reentering bodies; that is, the phenomena that can be observed either by radar or optical devices during reentry and the "forgery" possibilities of reentry decoys. The "plasma sheath" has assumed a new importance in this work, since it provides a radar target. Laboratory studies conducted by means of shock tubes, arc jets, ballistic ranges, and other experimental facilities are being pursued hand-in-hand with field studies of actual reentries. Down-range observations are made both from the surface (on land or ships) and from specially equipped aircraft flying in the reentry area.

While combustion-driven shock tubes were capable of simulating gas conditions at shock speeds comparable to satellite reentry velocities, the imminence of lunar and interplanetary flights pointed out the necessity of developing shock tubes of higher performance. The electric arc-driven shock tube, which can attain shock velocities of more than 40,000 feet per second, was perfected during the early 1960's. This type of shock tube has played an important role in determining the reentry conditions to be encountered on these higher energy missions, such as Project Apollo.

As we have seen, studies of high-temperature gas dynamics have provided one means of investigating highly ionized gases, or plasmas. Often referred to as the "fourth state of matter," plasmas represent literally a new domain to the physicist: a field of research with problems and potentialities of its own.

For example, it had been known since Faraday's time that an electrically conducting gas could, in principle, generate an electric current when passed through a magnetic field. In the early 1950's, shock-tube studies by Brogan and Rosa*† showed that the noble gases and air could be made to generate electricity when seeded by small amounts of easily ionized material, such as cesium or potassium. In 1958, Rosa‡ succeeded in producing 10 kilowatts in a magnetohydrodynamic (MHD) power generator. Since that date, development of MHD generators has been pursued actively in the United States and several other nations, including Japan, England, France, and Russia.

By applying knowledge of plasma conductivities, high-temperature materials, and aerodynamics – all gained in part through reentry studies – it has become possible to develop practical combustion-fired MHD generators.

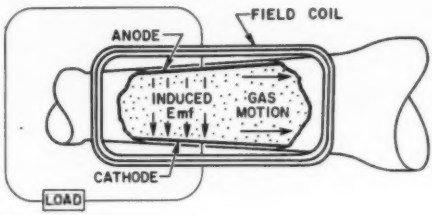


Figure 4 – Schematic of a D.C. magnetohydrodynamic generator. Note that the magnetic field, gas flow, and induced electromotive force (emf) are mutually perpendicular.

In its simplest conceptualization (Figure 4), the MHD generator is little more than a pipe through which the plasma flows, driven by a pressure gradient. Electrodes are placed in the pipe, which is surrounded by a magnetic coil. As the plasma flows through the magnetic field, a voltage is induced between the cathode and anode. Power is extracted by connecting the electrodes to a load. Except for the replacement of a solid armature by the plasma, the basic principle of operation is the same as that for conventional rotating turbine generators. MHD generators, however, offer promise of being more efficient than turbogenerators, since they contain no mechanical moving parts and can handle much higher temperatures than rotating machinery.

To date, practical MHD generators have been restricted to combustion heat sources utilizing fossil fuels, because only such heat sources can provide high enough temperatures to thermally ionize the working

*Rosa, R. J., "Part I: Shock Wave Spectroscopy," and "Part II: Engineering Magnetohydrodynamics," Thesis, Cornell University, 1956.

†Brogan, T. R., "Conduction of Electrical Currents to Cold Electrodes in Shock Tubes," Thesis, Cornell University, 1956.

‡Rosa, Richard J., "Magnetohydrodynamic Power Generation Using Nuclear Fuel," Avco-Everett Res. Lab. Res. Rept., Mar. 1960.

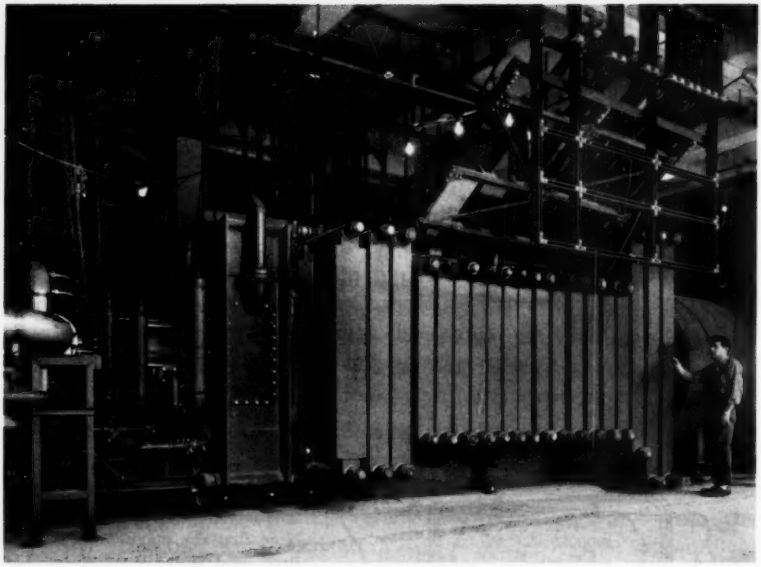


Figure 5 – Mark V 20-megawatt self-excited magnetrohydrodynamic generator that employs a modified rocket engine to produce high-temperature ionized gas.

plasma. One such generator (Figure 5), which utilizes a rocket-engine type combustion chamber, has produced 20-megawatts net power output, plus approximately 12 megawatts to drive its field coil. A similar MHD generator is now under construction at the Air Force Arnold Engineering Test Center in Tennessee, where it will provide the power for the LORHO 20-megawatt hypersonic wind tunnel. Matched to this MHD generator will be a 20-megawatt MHD accelerator that will drive the wind tunnel itself. This 20-megawatt installation is the prototype for a 300-megawatt generator-accelerator system for a larger wind-tunnel facility.

MHD generators, which now have reached the stage of practical applications for short-time power needs, are being developed also for commercial central-station generating plants. Work to date has proved the feasibility of this concept. Avco Corporation, working in partnership with a group of electric utility companies,* is planning an experimental

*American Electric Power Company and its subsidiaries – Appalachian Power Company, Indiana and Michigan Electric Company, Kentucky Power Company, and Ohio Power Company – The Dayton Power and Light Company, Illinois Power Company, Indianapolis Power and Light Company, Louisville Gas and Electric Company, Union Electric Company, and The United Illuminating Company – with American Electric Power Service Corporation acting as agent for the utility group.

pilot plant to produce practical operational data on an MHD generating station for commercial applications.* It has been estimated that coal-burning MHD central-station power plants could save the Nation approximately one billion dollars per year on fuel costs for electric power generation.

The eventual goal of employing nuclear reactors as heat sources for MHD generators is also under study. At present, nuclear reactors do not produce the high gas temperatures necessary to thermally ionize the seeded working fluid. However, small-scale experiments have shown that nonthermal ionization is possible under certain conditions and can result in plasma conductivities high enough to produce power in an MHD generator. In addition, nuclear reactors can be designed to yield higher gas temperatures.

Essentially, the MHD generator converts plasma kinetic energy to electrical energy. It is also possible to reverse this process and use electrical energy to add to the kinetic energy in a plasma. This is the purpose of the MHD accelerator in the LORHO wind-tunnel facility described in a preceding paragraph. Recently, the concept of using an MHD accelerator to improve the performance of shock tubes was demonstrated.† The MHD Augmented Shock Tube utilizes an accelerator to add energy to the driver gas of the shock tube. Shock velocities of more than 15 millimeters per microsecond have been obtained in preliminary experiments with this device.

The temperature range just above that accessible to the arc-driven shock tube is the interesting domain in which plasmas become fully ionized and the phenomena associated with multiple ionization appear. The mean free path of a particle in a fully ionized plasma varies (at constant density) as the square of the temperature. Therefore, at extremely high temperatures collisions between particles become very rare. One of the most intriguing aspects of plasma dynamics is the study of such collision-free plasmas. Many astrophysical phenomena are connected with the dynamics and dissipation mechanisms in such high-temperature plasmas, and the central problem in the production of a controlled thermonuclear fusion reactor is the magnetic containment of collision-free plasmas. Other exciting applications, such as space propulsion and radiation shielding, are possible also in this domain.

A number of experimental devices have been developed to study high-temperature plasmas. At Avco-Everett Research Laboratory, the

*Sporn, P., and Kantrowitz, A. R., "Five Years of MHD Generation Development," Avco-Everett Res. Lab. AMP 161, Apr. 1965.

†Leonard, R. Leon, and Rose, Peter H., "An MHD Augmented Shock Tube," Avco-Everett Res. Lab. AMP 168, Aug. 1965.

Magnetic Annular Shock Tube (MAST) has been the primary tool for these investigations.*

The MAST consists essentially of two concentric cylinders and an annular working space, which is located between the cylinders (Figure 6). There is no diaphragm; the driving force that produces the shock is provided by electromagnetic energy. The annulus is surrounded both outside and inside by coils which produce axial and azimuthal magnetic fields in it. The axial field, which runs lengthwise through the annulus, keeps the working gas from touching the cylinder walls. The azimuthal field produces circular lines of magnetic force within the annular working space.

Hydrogen gas of low density is admitted to the working space. The azimuthal and axial fields are established. A 40,000-joule electrical

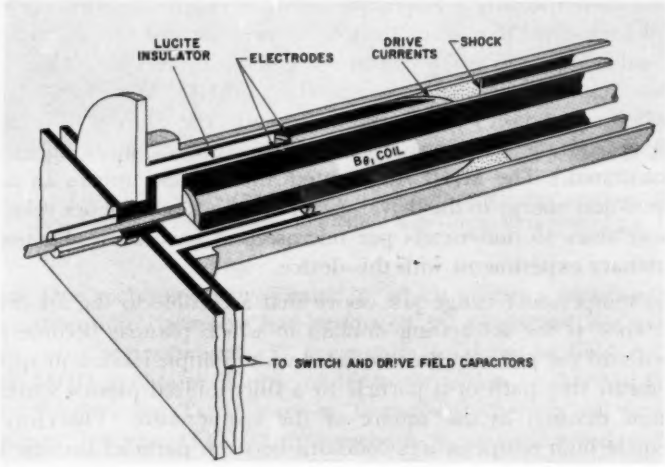


Figure 6 — Schematic drawing of the Magnetic Annular Shock Tube (MAST). This device consists essentially of two coaxial cylinders between which a radial electric field is imposed suddenly by switching on a condenser bank. The gas at the left and adjacent to the lucite is preionized, the switch is closed, and, ideally, a radial-drive current sheet is formed uniformly around the annulus. The magnetic field generated by this current sheet drives the gas in the shock tube. A shock wave moves ahead of the driver currents. The tilting of the current sheet is caused by the higher magnetic pressure at smaller radii. The rod down the centerline can be used to produce an azimuthal magnetic field ($B\theta$), which serves to contain the plasma that has been compressed and heated by the shock. Provision is made also for placing solenoids around the MAST to make possible the use of axial containing fields.

*Camac, M., Kantrowitz, A. R., Litvak, M. M., Patrick, R. M., and Petschek, H. E., "Shock Waves in Collision-Free Plasmas," Avco-Everett Res. Lab. Res. Rept. 107, Aug. 1961.

impulse is discharged in two microseconds from a pair of cylindrical electrodes that ring the inner and outer circumference of one end of the annulus. The shock wave forms ahead of this discharge and travels down the 30-inch-long tube in about two microseconds, reaching a maximum speed of 60 centimeters per microsecond (about one million miles per hour). It heats the plasma to several million degrees Kelvin.

The shock waves produced in the MAST are identified by several means. First, the light intensity produced by the shock front agrees with the predicted plasma density behind the shock. Second, the measured shock velocity agrees with the amount of energy put into the magnetic-field driver, as required by the conservation of momentum. Finally, the compression of the magnetic field across the shock front has been shown to be that which is predicted theoretically.

The existence of a shock wave that is considerably thinner than a particle mean free path required the development of new theories to explain how energy can be dissipated through plasma-wave interactions. An equation, similar to the Boltzmann equation for shock-wave dissipation for collision-dominated shocks, has been derived.

Another experimental tool for studying collisionless plasmas is the Magnetic Annular Arc Accelerator (MAARC), which has been developed into a plasma wind-tunnel facility that can simulate many features of the interplanetary plasma and the solar wind. Essentially, the MAARC is an electric arc jet to which a magnetic-field coil is added in such a way as to produce additional acceleration to the arc-heated plasma. The resulting MHD forces acting on the plasma accelerate the flow without increasing the plasma temperature; thereby, more directed energy is imparted to the plasma flow than would be possible through use of an arc jet alone.*

The domain of physical phenomena accessible to the MAST and MAARC and similar devices is an exciting one. Not only is this realm of fully ionized plasmas largely unexplored experimentally, but it is known to be the realm of astrophysical phenomena. The thermonuclear reactions taking place in the core of the sun and stars (and, hopefully, those that will take place eventually in man's thermonuclear reactors) lie in this region of physics. The MHD phenomena responsible for solar flares, interplanetary shock waves, and terrestrial magnetic storms are also in this domain.

Significantly, the Office of Naval Research is one of the agencies supporting investigations of plasma physics. If this support of a promising new area of research reaps the same measure of benefits as did the support of the earlier shock-tube work, the next 20 years should be even more stimulating and rewarding than the past two decades.

*Patrick, R. M., and Pugh, E. R., "Laboratory Simulation of Solar Wind Phenomena," Avco-Everett Res. Lab. Res. Rept. 234, Oct. 1965.

ONR's Role in Boron Chemistry

Vicennial Article

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Chemistry Branch
Office of Naval Research

Research sponsored by the Office of Naval Research since 1946 has led to the discovery of a whole new field – the chemistry of the carboranes – and to the creation of novel polymeric materials, including plastics and rubbers, which are stable up to 700°F. Largely through this research, the field of boron hydride chemistry has been established, endowed with guiding theories and implemented by intensive experimental research in many laboratories. The carboranes, constituted by molecular arrays of carbon, boron, and hydrogen atoms, can be derived from the boron hydrides by replacing some of the boron with carbon. The polymeric materials have been prepared from carboranes or boron hydrides by our contractor, the Olin Mathieson Chemical Corporation, and are being developed into useful materials having entirely new combinations of properties by the Bureau of Naval Weapons and the Bureau of Ships. Industry also has begun to show active interest in these polymers (short for polymeric materials) although they were first described only three years ago. ONR accomplished these things by selecting, beginning in 1946, a few subjects for intensive research and then sustaining the work for nearly 20 years. Research on compounds of boron was preferred to research into the chemistry of most of the other hundred odd elements for reasons that become apparent farther along in this discussion.

Research into physical methods for the determination of chemical structure also was given high priority by ONR, especially the methods of nuclear magnetic resonance (NMR) and of X-ray diffraction at low temperatures, at which materials that occur ordinarily as gases or liquids can be obtained as crystals. ONR takes credit for accepting the proposal of H. S. Gutowsky, University of Illinois, who has collaborated with the Office of Naval Research for more than 15 years in chemical applications of NMR and thus was among the few "firsts" in this field. NMR had a necessary part in the discovery and development of the carboranes during the period 1958-1966. Likewise, X-ray diffraction at low temperatures, developed in collaboration with this Office by W. N. Lipscomb, first at the University of Minnesota (1949-1958) and then at Harvard University, was necessary in the elucidation of the structures of the boron hydrides and carboranes.

One may say then that along with some 20 other fields of research, the Chemistry Branch of the Office of Naval Research has preferred to support work on a chemical problem, the chemistry of boron hydrides

and their derivatives, and on a partly physical problem, the power of the use of certain phenomena of absorption and diffraction to probe into chemical structures.

What then was the scientific background of the ONR research into boron hydrides? Organic chemists, who investigate the hydrocarbons and their derivatives, had had the benefit of fruitful theories for nearly 100 years and had built the imposing edifice we know as organic chemistry. It has been said, by chemists to be sure, that the structural theory of organic chemistry, introduced during the period 1858-1865 by A. Kekule and others, is one of the great intellectual achievements of man.* The structural theory of the boron hydrides and the carboranes was introduced during the period 1954-1965 by contractors of the Office of Naval Research, particularly Lipscomb and his associates. Boron is next to carbon in the periodic table of elements. The boron nucleus has one unit of charge less than carbon, holds one fewer electron, but in spite of this electron deficiency for bonding to other atoms does form molecules containing chains of boron atoms. The formation of chains of carbon atoms is a central feature of organic chemistry. There, the bonds are conceived as two-center bonds, each pair of atoms sharing the binding electrons. In the fascinating theory of boron chemistry, multiple-center bonds and a limited number of distributions of the electrons in space, called "molecular orbitals," are much used concepts. The materials of organic chemistry in 1946 consisted of about one million different chemical compounds, of which a few thousands were hydrocarbons and the remainder derivatives, such as the sugars, which are made by the combination of carbon, hydrogen, and oxygen. In 1946, only six boron hydrides had been reported and there were less than 30 derivative compounds. Moreover, a satisfactory theory for the arrangement of the boron and hydrogen atoms in the boron hydrides was lacking. These hydrides were misfits in the available system of theory. They had been discovered and described in the period 1912-1936, and although a number of the foremost theoreticians, L. Pauling and R. S. Mulliken among them, wrote about them in the 1930's, it was not until 1954 that our collaborators, Eberhardt, Crawford, and Lipscomb of the University of Minnesota, proposed theories for the correlation of boron hydride composition and structure with capability of existence and relative stability. This work was continued by Lipscomb, who, in 1962 predicted the stability of the three isomeric carboranes which contain two atoms of carbon for each ten atoms of boron in the molecular (icosahedral) cage. At the time, two of the three isomeric carboranes had been discovered and were reported in the confidential military literature as

*_Chemistry: Opportunities and Needs._ 1965, p. 2. National Academy of Sciences—National Research Council.

results of research on high-energy fuels sponsored by the Air Force and the Navy, but these experimental events were not known to Lipscomb and his collaborator, R. Hoffmann. These are the two carboranes from which the ONR contractor, Olin Mathieson Chemical Corporation, and the Bureau of Ships contractor, Thiokol Chemical Corporation, Reaction Motors Division, produced the polymeric materials which are now being developed further.

Returning to ONR's role in boron hydride chemistry, we remember that the chief military interest in the boron hydrides in 1946 appeared to be their reaction with air and water to produce fire and noise.* The first ONR project in this field was directed by A. B. Burg of the University of Southern California and was entitled "Water-Reactive Compounds." Some time after 1952, when Burg discovered derivatives of a boron hydride which remained unchanged in steam, the title of the project was changed to "Boron Chemistry," and so it remains to this day. One important result of this discovery of Burg was, of course, the direction of attention to the possibility of incorporating boron hydride moieties into very stable materials. This has been realized in the high-temperature-resistant polymers prepared by Olin Mathieson Chemical Corporation from a carborane. However, in 1946 the boron hydrides were potential propellants, and a strong program of research on their thermodynamic properties was supported by ONR.

With regard to the structures of the boron hydrides known in 1946, the definitive papers for diborane, B_2H_6, appeared during the period 1946-1948, but important confirmation of the structure now accepted was provided in 1951 by the electron diffraction study of K. W. Hedberg and V. Schomaker, California Institute of Technology, which was sponsored by ONR. Lipscomb reported an X-ray study of beta-diborane in 1965. The structures of tetraborane, B_4H_{10}; pentaborane-9, B_5H_9; pentaborane-11, B_5H_{11}; and hexaborane, B_6H_{10} were established in the 1950's by X-ray diffraction by Lipscomb and co-workers. This work was sponsored by ONR. The structure of decaborane, $B_{10}H_{14}$, was established by X-ray diffraction by J. S. Kasper, Lucht, and D. Harker at the Polytechnic Institute of Brooklyn. This research, the results of which were published in 1950, was not supported by ONR. About 20 other compounds containing only boron and hydrogen have been reported since 1950. Thus more hydrides of boron are known than of any other element except carbon. The structures of ten of these hydrides have been determined in Lipscomb's laboratory by X-ray diffraction. The power of this method is indicated by Lipscomb's

*For relation to the borane high-energy fuel program of the 1950's see "The Basic Chemistry of Boranes and Their Derivatives: A Critical Survey." 1964. Vol. 1, pp. 1, 272, 303. Prepared by Midwest Research Institute for the Advanced Research Projects Agency.

statement* that although no chemical analysis has yet been made on nonaborane-15, B_9H_{15}, the composition and structure have been established from the X-ray data alone.

Now, what about the carboranes? The first two were discovered experimentally by workers in the high-energy fuel program of the Department of Defense in 1958, but were not reported in the open literature until 1963! However, they were conceived by Lipscomb before 1960 when, in connection with his broad development of boron hydride theory, he asked this question: What kind of chemical species will result if we replace a boron atom in a given boron hydride by carbon? Descriptions of some such hypothetical carbon-boron hydrides (carboranes) were published by Hoffman and Lipscomb in 1962. The Lipscomb theory indicated that replacement of two borons in dodecaborane-12, $B_{12}H_{12}^{-2}$, by carbon should give three, and only three, very stable compounds of the composition $B_{10}C_2H_{12}$. The two carboranes discovered in 1958 have this composition. The third was found by experiment in 1964 by the ONR contractor, Olin-Mathieson Chemical Corporation. These three isomeric compounds are very stable. The orthocarborane is stable at temperatures below 750°F and metacarborane, at temperatures as high as 900°F. At temperatures above 900°F, the meta-carborane is partly converted to para-carborane. It is the meta-carborane moiety which has been incorporated into polymeric chains to make rubbery materials.

Why is the chemistry of the carboranes, thus opened up, a new field of great importance? Why do we dare compare its potentialities with those of organic chemistry? It is because both theory and experimental evidence tell us that these compounds have entirely new properties. To be sure, alkyl boron hydrides have been prepared, and these, of course, also are constituted of boron, carbon, and hydrogen. But these compounds were conceived on old theory and have the properties of organic compounds plus the properties of the boron hydrides. However, the carboranes are stable at much higher temperatures. Their chemistry can be understood if one postulates polyhedral molecular geometries in which each carbon atom is surrounded by a larger number of atoms than it is in organic compounds. The three carboranes already mentioned have icosahedral geometry. Others now being investigated intensively have other arrangements of the atoms. Present directions of development of the field include (1) the chemistry of carboranes $B_mC_nH_{m+n}$, containing fewer than ten atoms of boron; (2) the chemistry of carboranes containing numbers of carbon atoms other than two and those containing boron, carbon, and hydrogen in ratios other than 5:1:6; (3) the chemistry of derivatives

**Boron Hydrides*, by W. N. Lipscomb. 1963. p. 6. W. A. Benjamin, Inc. New York. Amsterdam.

of the carboranes in which various numbers of the boron atoms are replaced by atoms of other elements, including metallic elements; (4) the chemistry of derivatives in which the hydrogen atoms attached to boron are replaced by other elements; and (5) research to develop methods of preparing one pound quantities of some of these compounds.

The carboranes $B_3C_2H_5$, $B_4C_2H_6$, $B_5C_2H_7$, $B_9C_2H_{11}$, and B_5CH_7 have already been reported. The ionic $B_9C_2H_{11}^{-2}$, considered to be an icosahedral fragment, can be combined with an atom of iron or another metal to give very stable compounds, the molecular structure of which is representable by a complete icosahedron, as in the case of the three 10-boron carboranes. So boron chemistry offers one more example of the principle of stabilization by completion of certain shells of atoms.

There is little doubt that we are privileged to watch and to influence the early unfolding of a major field of chemistry. Some of the gross features are clear already, but new ones are bound to appear. Also, much fine detail must be provided by more research, and such detail can be critical in the development of new materials. The B-10 carborane that we have already employed remains unchanged for hours at 800°F and decomposes at 900°, but one of our contractors predicts that a B-8 carborane will be substantially more stable. Since this B-8 carborane is just becoming available, we may be able to observe its behavior at high temperatures within the next few months. We will withhold the name of the predictor until the greater stability is demonstrated. He had new theory to lead him to the discovery of $B_8C_2H_{10}$, but little more than intuition to point to the likelihood of $B_8C_2H_{10}$ being more stable than $B_{10}C_2H_{12}$.

What else do we see for the future? Carboranes in which boron is bonded to atoms of metals have been discovered during the past two years by M. F. Hawthorne, University of California at Riverside. There are many metals, each of which will give its particular contribution to the properties and capabilities of new materials. ONR will push hard in this metal-boron field in the years just ahead.

It must be evident now that thousands of new compounds, derivatives of the known carboranes in which hydrogen has been replaced partly or wholly by other elements, will be discovered and used. Even as we write this, the first carborane fluorides are being synthesized by an ONR contractor.

The Navy Marine Engineering Laboratory at Annapolis, Maryland, is building a multimillion dollar research complex which will recreate in the laboratory the environment encountered in the depths of the ocean. The laboratory is needed to develop equipment for efficient operation of deep-diving submersibles and instrumentation to be used in the deep oceans.

Research Origins of Modern Time and Frequency Control

Arnold Shostak
Electronics Branch
Office of Naval Research

Vicennial Article

Precise knowledge of the time of day and the ability to measure intervals of time exactly have long been of utmost importance in navigation and operations of maritime and naval units. In recent years, equal significance has emerged in the case of the measurement and knowledge of the frequencies of electromagnetic waves which man and nature generate over a broad range. This trend is natural, as phenomena involved in time measurements often are observed to be periodic, so that frequency of oscillation and cyclic times are in reciprocal relation.

Many operations and techniques of our daily lives involve a knowledge of time. Military operations depend on the availability of reliable, precise time for the synchronization of clocks, for navigation, whether accomplished by means of sextants or artificial satellites, for communications, for electronic warfare, and for many guidance and fire-control systems. In the same way, knowledge and use of exact frequencies of electromagnetic waves have become essential elements in communications, whether generated for purposes of entertainment, or the transfer of information among Fleet units, or guidance of ships and aircraft by electronic navigation systems, such as low-frequency Loran and Omega. In addition, scientific experiments involving simultaneous observations of natural and man-made phenomena at widely separated stations on our globe depend on time synchronization. Research into the structure and distribution of particles which make up atomic and molecular systems, in turn, exploits extremely precise frequency-measurement techniques to yield information about jumps among energy levels of electrons and nucleons. Modes and amplitudes of excitation, rotation, and vibration and interactions of these elementary particles with electric and magnetic fields, as well as among the particles themselves, are deduced by frequency measurements which often involve some 11 or 12 significant figures of accuracy.

Giant strides in man's ability to measure time intervals and absolute frequencies have been taken within the last several decades. Whereas the best precision in time-interval determination in the period of World War II was in the order of microseconds, it is now possible to measure these intervals in the laboratory to about one part in 10^{11} — an improvement of five or six orders of magnitude in 20 years. Similarly,

frequency comparison now may be accomplished against laboratory primary standards which have intrinsic stabilities of approximately one part in 10^{12} or 10^{13}—improvements of some four or five orders of magnitude over the comparisons that could be made in the 1940's.*

Advances in technology of time and frequency determination were influenced vitally by the appearance of quantum-electronics devices known as atomic clocks, atomic-beam frequency standards, and masers (molecular amplification by stimulation of emitted radiation).

It is perhaps interesting to trace the evolution of a few of these devices from basic research in physics and electronics to prototype fabrication and the development of useful equipments. A review of the metamorphosis of modern precision time and frequency standards reveals clearly the contribution of a wide variety of disciplines in basic and applied research. As is frequently the case in the history of the evolution of ideas and inventions which have led the way to scientific and technological advances in our civilization (including radio, television, and modern arms), the atomic clock and the hydrogen maser were, in general, the products of the intellectual contributions and enterprise of a large number of scientists and engineers. It is true that the processes of illuminating the important principles behind these devices and transforming them into practical instruments were the feats of but a handful of investigators; however, research and study on the part of uncounted workers lie behind the ultimate advent of these useful devices.

The understanding of the processes involved in the atomic clock and hydrogen maser began with the discovery of the dispersion of light by Newton (1642-1727) and studies of the spectral composition of electromagnetic waves emitted and absorbed by various materials by Wollaston (1766-1828), Fraunhofer (1787-1826), Kirchhoff (1824-1887), and Bunsen (1811-1899). Then came the remarkable observations of Balmer (1825-1898), Paschen (after 1911), Lyman (1874-1954), and others, which gave integral relationships for frequencies and wavelengths in these processes. Rutherford (1871-1937) and Bohr (1885-1960) gave us the powerful model of the hydrogen atom, and Sommerfeld (1868-1950), Wilson (after 1869), and de Broglie (after 1892) made possible the extension and expansion of the laws of quantum theory to explain such matters as the particle-wave dualism of matter and the role of angular momentum in that theory. Goudsmit and Uhlenbeck, in 1925, postulated the contributions of electron spin to the determination of exact energy levels of atomic and molecular systems, and Pauli's (1900-1958) exclusion principle shed much light on the connection between chemical properties of atoms and their structure as revealed by spectroscopic means. The great contributions

*F. E. Terman, *Radio Engineers' Handbook*, Sec. 13, pp. 950-951, 1943.

of Planck (1858-1947), who was foremost in revealing the startling fact of quantization in matter; of Einstein (1879-1955), who, among his many contributions, developed means for calculating transition probabilities and intensities in spontaneous and induced jumps in atomic systems; of Stern, Gerlach, Estermann, Schrodinger, Heisenberg, and Dirac, all of whom were giants on whose shoulders stood those who applied their fundamental ideas to create useful modern devices, are well known to all scientists. Each added to the splendid mosaic which we regard as the state of physics today.

The direction and extension of broad, general knowledge of quantum processes that was gained prior to the 1930 period, and which led toward the development of atomic time and frequency technology, may be said to have been spearheaded by Dr. I. Rabi and his coworkers and students at Columbia University (including Townes, Zacharias, Ramsey, Nierenberg, Gordon, and Zeiger), by Lyons at the National Bureau of Standards, and by Hershberger at the Radio Corporation of America. Research on specific devices was promoted by Essen in England, by Daly, Grant, and McCoubrey of the National Company (Malden, Massachusetts), by Vessot of Varian Associates (Beverly, Massachusetts), and Andresen of the Army Electronics Command, among others. Much of the university and industrial laboratory research has been encouraged by the sponsorship given to it by the U.S. Department of Defense. In the Navy, considerable attention has been devoted to the subject by the Office of Naval Research, the Naval Research Laboratory, and the Naval Observatory, with the encouragement and assistance of the Bureaus of Ships and Weapons.

One finds, remarkably, that principles underlying operation of the quantum devices are fundamentally the same in each approach; namely, that the total energy (kinetic plus potential) of atoms or molecules, as well as the spatial orientation of magnetic moments of electrons and nuclei of these atoms and molecules (with reference to external magnetic fields), are quantized. In changing from one state to another, these atoms or molecules absorb or emit electromagnetic energy in accordance with the quantum condition, $E_2 - E_1 = h\mu$, where the E's are total energies of the states involved in the energy 'jump,' "h" is Planck's constant, and μ is the frequency of the electromagnetic wave absorbed or radiated in the process. Three main streams of effort in the last 20 years that have been based on these quantum processes may be traced.

Massachusetts Institute of Technology

A group under Professor J. R. Zacharias, of the Massachusetts Institute of Technology, Research Laboratory of Electronics, working under support of the Joint Armed Services Electronics Program and

following a suggestion made in 1944 by I. Rabi, of the Columbia University Radiation Laboratory,* was studying properties of cesium atoms by means of electromagnetic interactions with beams of neutral atoms. Resonances (absorption of the radio-frequency field by the neutral molecules) were excited by application of external magnetic fields to produce "Zeeman effect" energy levels in the cesium atoms. Neutral cesium atoms emerging from the oven which heats them electrically and directs them as a beam find themselves disposed in one or the other of two energy levels of concern. These levels, termed "hyperfine," come about from the interaction of nuclear and outermost electron magnetic moments of the cesium atoms. When these moments are parallel, a higher energy state is evidenced, and when they are anti-parallel, the atom is in its lower state. Interaction of the inhomogeneous external (deflecting) magnetic field causes different transverse displacements of the cesium atoms of the beam, resulting in the separation of the higher level atoms from the lower level ones. This process is known as "state separation." Means for accomplishing state separation, by design of carefully controlled inhomogeneous magnets, and means for detecting absorption resonance frequencies, corresponding to "flipping" of the lower state atoms to higher energy levels, were evolved. One such detector took the form of a hot wire which ionized the neutral atoms to change them into charged ions. Electrons spewing from the latter were then detected with photomultiplier tube instrumentation.

States which were little affected by the magnetic field were studied intensively. Those of Cs^{133} showed resonances at 9192.63197 megacycles and line widths of about 200 cycles per second. By splitting the line widths to about 1 percent under these conditions, it was possible to obtain stabilities of about 1 part in 10^{10}.

Detailed investigations of magnetic materials and configurations were conducted successfully to produce precisely known transverse inhomogeneous state separating fields that could serve as useful signal sources for radio-frequency energy at "X" band (3 centimeters). In addition, Ramsey's separated field method† was exploited to permit extended interaction of the cesium atoms with the external magnetic field.

A simplified arrangement of Professor Zacharias' apparatus is shown in Figure 1.

Cesium is heated electrically in the oven, whose openings create a directional beam. The field of magnet A deflects neutral atoms of

*The Columbia Radiation Laboratory was set up in 1942 to develop centimeter wavelength radio-frequency sources for radar use. It was kept in operation by agreement between Columbia's Physics Department and the Joint Services in 1945, and it has continued as an outstanding contributor in millimeter and microwave spectroscopy and related fields of physics and electronics.

†Ramsey, N. F., *Molecular Beams*, Oxford University Press, 1960.

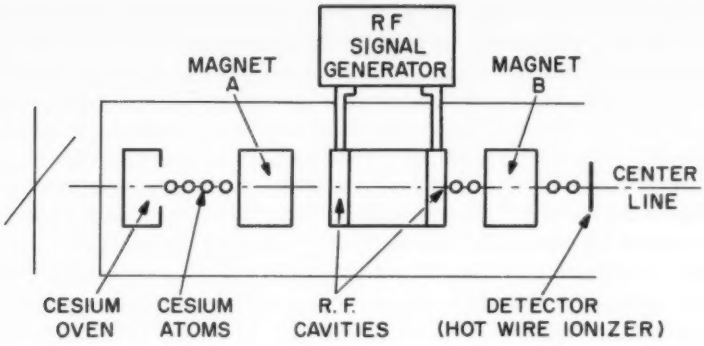

Figure 1

magnetic moment μ with a transverse force proportional to the transverse gradient component of the magnetic field H. Thus,

$$\left(F_z = \mu \frac{\partial H}{\partial z}\right).$$

After a transition of the atoms has been accomplished in the radio-frequency cavities (the magnetic field of the radio-frequency signal interacts with the atom's magnetic moment, stimulating it from the higher to the lower state), the field of magnet B is encountered, which deflects the beam back to its original center-line direction of movement. (It is important to note that the stimulating "flipping" will occur in the cavities only when and if the applied radio signal, as from a klystron source, is of the frequency corresponding to the quantum jump between higher and lower states of the cesium atom.) When the beam now hits the hot wire (tungsten) ionizer, the cesium atoms are ionized, giving off electrons which are detected in a secondary electron photomultiplier. Substantial current from the photomultiplier tube circuits means that the klystron is on frequency, that the beam is on the center-line, and that magnetic deflections are occurring. Diminution of the photomultiplier current results in actuation (via phase-comparison detection) of feed-back loop energy which changes the source frequency by thermally changing the klystron cavity dimensions as a function of frequency drift. This mechanism keeps the source klystron on the same frequency for long periods of time. It is this klystron output which is compared, by beat frequency methods, with harmonic frequencies of reference quartz piezo-electric crystals. These last, in turn, actually drive clocks which give the time of day.

With cooperation of the Bureau of Ships (R. B. McDowell), the Bureau of Aeronautics (J. M. Brearley), and the Naval Research

Laboratory (H. Hastings and R. O. Buchanan), an outline of characteristics of an engineered version of Dr. Zacharias' atomic clock was framed. An Office of Naval Research contract was let with the National Company, Malden, Massachusetts, to produce military-style equipment. The contract, dated January 1955, sought "a small stable frequency and time source, which included instrumentation to assure that sharpest lines, maximum stability, and restability of the cesium atom device would be obtained." The first production, called "Atomichron," developed by the National Company arrived for test and evaluation at the Radio Techniques Branch, Naval Research Laboratory, early in 1956. Since then, it and its descendants have served well as reference standards for the Navy.*

Columbia University Radiation Laboratory

Ammonia, NH_3, was among the gases which the Columbia University group, under partial ONR sponsorship, was investigating. This gas had been shown by Cleeton and Williams† to absorb microwave energy in the 1.25 cm band. (Other absorptions had been known to occur in the 60- to 100-micron infrared band.) Ammonia has the interesting molecular structure shown in Figure 2:

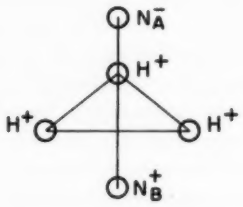

Figure 2

Three hydrogen atoms are arranged equidistant from each other in a plane, while the nitrogen atom may vibrate on a line normal to that plane. Two positions of minimum potential energy exist for the molecule, one corresponding to the nitrogen atom, position A, and the other to position B. It is possible, owing to the wavelike character of matter, for the nitrogen atom to "tunnel" through the positive plane of the hydrogen atoms; the tunneling occurs because the nitrogen atom wave function (which describes the probability of finding the atom

*Prior to delivery of the National Company unit, a breadboard cesium-beam clock was constructed and operated by D. L. Essen of the National Physical Laboratory in England. Dr. Essen determined the frequency of the cesium-beam device to be 9,192, 631,830 ± 20 cps, in terms of the second of Ephemeris time (ET).

†Cleeton and Williams, *Physical Review*, Vol. 45, p. 234. 1934.

at any point) has a finite value on both sides of the hydrogen plane. The existence of two potential energy minima means that there are two levels of total energy of NH_3 which correspond to these minima. Absorptions of transitions between these energy levels are referred to as "inversion" spectra; they occur at about 23,870 Mc.

Professor Townes and colleagues J. P. Gordon and H. J. Zeiger,* by means of an ammonia gas beam whose upper- and lower-state molecules had been separated by inhomogeneous electrostatic fields (much as Zacharias had separated cesium atom states by transverse deflections caused by magnetic fields), created the first "maser" in 1954. The point of difference between the cesium apparatus and the ammonia device was that, whereas in the former, a radio-frequency field caused transitions between lower and upper states of cesium atoms, in the latter, jumps between upper and lower molecular levels were caused by two other means: first, by thermal (Johnson) noise in the gas-filled maser cavity (this cavity having been filled with electromagnetic fields); and subsequently, by the stimulating action of those fields on the ammonia gas, which caused its molecules to jump from upper to lower levels, with emission of the 23,870 Mc signal. Townes and other investigators studied oscillation conditions of the NH_3 maser, natural breadths of the oscillation lines (about 4000 cps), power output (about 10^{-10} watts), and other properties of the ammonia devices.

Although the NH_3 maser oscillator has high inherent stability and was, in fact, proposed to be engineered into a reference standard at the Naval Research Laboratory (as had been attempted by H. Lyons, of the National Bureau of Standards),† it lacks some of the desirable features of the cesium-beam technique. These are (1) that cesium can be handled as a solid until boiled and (2) that cesium-resonant frequencies are lower than those of ammonia and thus closer to frequencies of communications and radar apparatus; therefore, less auxiliary equipment is required for practical frequency-comparison purposes.

It may be said that Townes' contribution was most important to the physical sciences in that it brought about the first active maser.‡ Soon, other proposals were made for replacing the two-level method with three-level schemes,§ in which "pumped" energy would put the system in energy level 3 from level 1; thereafter, stimulated emission was established by interaction of an incoming signal with the atomic system involved. Amplification of incoming microwave energy of frequency μ_{32} (which is the stimulating signal) comes about when the energy of stimulated emission is added to that of an incoming signal in a

*Gordon, Zeiger, and Townes, *Physical Review*, Vol. 95, p. 282 (1954), Vol. 99, p. 264 (1955).

†Lyons, H., Ann. N. Y. Acad. Sci., Vol. 55, p. 831. 1952.

‡Trans. IRE-PGED-3, 1953.

§N. Bloembergen, *Physical Review*, Vol. 104, p. 324, 1956.

microwave cavity. A great variety of three-level masers and lasers, many of the latter operating on the energy levels of the red-tinting chromium atoms of ruby glass, have been studied and have found their way into use as low-noise receivers for radio astronomical observations,* for guidance, for range finding, and in many other applications. (Lasers are masers operating in the extremely high frequency ($\cong 10^{14}$ cps) region and in which the microwave resonant cavity is replaced by precisely parallel mirrors between which the electromagnetic energy stands.)

In the course of research at Columbia, a rhubidium (Rb^{87}) active oscillator, somewhat along the lines of the ammonia unit, but smaller and with higher inherent stability, was evolved. The oscillator, which operates at 6835 Mc and has an anticipated long-term stability of 1 part in 10^{12}, may be useful as an airborne frequency or time unit. This novel maser cleverly suppresses unwanted spontaneous emissions among numerous transitions of the rhubidium atoms by absorbing the microwave energy of these transitions through interaction with buffer isotopes of this element. Support for work on this maser was granted by the Office of Naval Research in 1964.

Harvard University

In another research laboratory, that of the Harvard University Physics Department, Professor N. F. Ramsey and colleagues were studying the effects of wall coatings of saturated hydrocarbons on the resonance lines of cesium atoms, hoping to find materials which could minimize the wall effects in broadening these lines. This work was sponsored by the Nuclear Physics Branch of the Office of Naval Research.

In the course of these investigations, it was deduced that, whereas in the case of cesium, resonances could still be observed after 200 wall collisions, in the case of the saturated hydrocarbons (owing to the light mass of hydrogen atoms), the tolerable number of wall collisions might exceed 100,000 before oscillations of individual atoms were lost. This reasoning was confirmed in 1962, when Professor Ramsey implemented the atomic hydrogen maser in the form of two laboratory units which, upon beating one against the other, delivered a relative frequency stability of 1 part in 10^{12}.

Energy-level jumps involved in the atomic-hydrogen device are the hyperfine transitions which occur as a result of magnetic interaction between nuclear and electron moments of the hydrogen atom. See Figure 3. Because both the nucleus (proton) and electron are spinning, are of finite radius, and are electrically charged, magnetic fields are

*C. H. Townes, *Radio Astronomy*, Cambridge University Press, 1957.

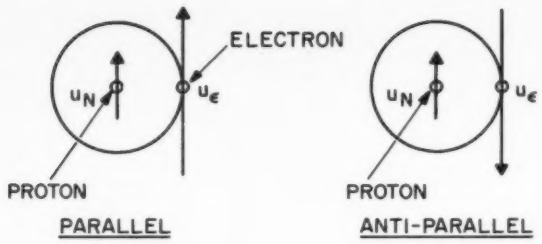

Figure 3

created about each, with corresponding magnetic moments. A priori, nuclear and electron magnetic moments may be parallel or anti-parallel to each other, thus giving rise to two possible energy levels (*i.e.*, when parallel, repulsion interaction may occur, whereas when anti-parallel, no further repulsion can take place). Jumps occurring either by forced absorption or by spontaneous radiation then may be measured and exploited.

With the realization of the utility of a standard which in the course of additional research could possibly obtain a stability of 1 part in 10^{13} and with financial assistance from the Bureau of Ships, ONR enterec into a contract with Bomac Laboratories, Inc., Beverly, Massachusetts, to engineer the Ramsey-conceived atomic-hydrogen standard. Engineering consisted of taking the device "from a course, laboratory-type experimental configuration to a research tool of practical physical size, with input (in the form of 10^{19} atoms of nascent hydrogen per second) from attainable ion sources and output in the form of electromagnetic energy at 1420 mc/sec." In the process of engineering this precise device, Bomac scientists and engineers studied hydrogen-source techniques, useful state-separating magnetic arrangements, radio-frequency cavity geometries and fabrication, and means for controlling quartz-crystal oscillator frequencies by feed-back loop methods.

In the summer of 1964, Bomac delivered two atomic-hydrogen masers, shown in the picture of Figure 4, to the Radio Techniques Branch, Naval Research Laboratory, for test, evaluation, and use. These units have operated successfully for more than a year. With the collaboration of Harvard, Naval Observatory, Naval Research Laboratory, and Bomac scientists, it was found that the atomic hydrogen standard operates (best determined value) at 1420.405773 cps, in terms of UT-2 time.*

*See definitions of Appendix A.

Figure 4 — Atomic hydrogen masers. The units were built by Bomac Laboratories under contract to ONR and evaluated and used by the Naval Research Laboratory.

The relative stability of two NRL hydrogen masers beating together is 2 parts in 10^{13} per week. Long term stability is now being investigated.

Very recently, Professor Ramsey proposed a modification of the hydrogen maser which may bring about an order of magnitude improvement (10 times) in stability of the present Bomac-type apparatus. With ONR support, the Harvard group will seek to reduce line-width broadening produced in the hydrogen-gas quartz flask container when the diameter of that container is made about 60 inches in lieu of the 10 inches of its present arrangement. Results of this research will be apparent about mid-summer 1966. If successful, several fundamental experiments in relativity, which depend on the ability to measure time to about 1 part in 10^{14}, may be performed for the first time.

Thus, one is able to trace the evolution of these practical, operational components and systems from founts of fundamental research through prototype fabrication and ultimate engineering. What is true in the case of atomic clocks and frequency standards has been shown to be equally true with respect to transistors, tunnel diodes, parametric amplifiers, ferrite circulators, and other modern devices.

The availability of refined measurement methods and instruments has permitted the Navy, in the main through the Time Service Division of the Naval Observatory, to deliver precise units of time to all the world and to keep track of the relation of atomic time to Universal Time and to Ephemeris time. Supplemental to time and frequency signals transmitted from stations WWV, Beltsville, Maryland, and

WWVH, Hawaii (operating in the 2.5 to 25 Mc intermediate frequency bands), the Navy has been sending stable frequency and phase transmissions in the 14 to 25 kc range from NBA, Balboa, Canal Zone; from NAA, Cutler, Maine; and from other very low frequency stations. The VLF station seconds pulses are sent in the UT-2 time reference. However, the clock which controls the VLF timing is actually an atomic clock. Information on the amount of offset between atomic time (A-1) and Universal (UT-2) time transmitted is broadcast periodically. Phase comparison observations of signals received from several VLF stations, whose carriers are maintained constant in this way, are yielding much information on the vagaries of the ionosphere and on other natural phenomena of importance in systems design and operation.

Although available precision and stability derived from these sophisticated time and frequency instruments and methods already seem to exceed actual military, civilian, and economic requirements, the Navy research program will continue to press for techniques of increasingly higher precision, making available research tools for scientific experimentation that could lead to unknown fields of discovery and ultimately to improved weapons.

Common Terms in the Measurement of Time

1. *Apparent Solar Day:* The interval between successive sun crossings of the local meridian.

2. *Local Apparent Time:* Time on any meridian, measured by the hour angle of the observed sun.

3. *Mean Solar Day:* The time it takes the earth to rotate once about its axis, as observed by the rising and setting of a fictitious sun. This mean sun is assigned a daily motion which averages out the irregularities caused by inclination of axis of rotation of the real sun.

4. *Tropical Year (or Mean Solar Year):* The time it takes the earth to revolve about the sun, as reckoned from the vernal equinox, or first point of Aries.

5. *Local Mean Time:* May be computed from apparent solar day by use of the "equation of time." This takes into account the fact that the sun does not move at a uniform rate along the ecliptic. The equation of time may be found in the "Nautical Almanac."

6. *Greenwich Civil Time:* Also called Universal Time (UT). It is Local Mean Time as measured at Greenwich, England.

7. *Universal Time (UT):* See also Greenwich Civil Time. A corrected value of Universal time (UT) to account for observed motion of the geographic poles and for the extrapolated annual variation in the earth's rate of rotation is called UT-2.

8. *Atomic Time (A-1)*:* A clock which keeps A-1 time advances one second in the interval requiring 9,192,631,770 oscillations of cesium at zero field. At Oh, Om, and O, UT-2 time on January 1, 1958, the value of A-1 time was Oh, Om, and Os.

9. *Ephemeris Time (ET):* Is based on the revolution of Earth around the Sun. The Ephemeris Second is defined as 1/31,556,925.9747 of the tropical year 1900. One second of ET is almost equal to one second of Mean Solar Time.

10. *Sidereal Time:* Duration of Earth's rotation with respect to the stars. The calculated relation between sidereal time and mean time is tabulated for each day in the *Nautical Almanac.*

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*Naval Observatory Time Service Notice No. 6, Jan. 1, 1959.

Space Research: Directions for the Future

In view of the Navy's past and continued support and conduct of astronomical research, the second report in a series entitled "Space Research: Directions for the Future," prepared by the Space Science Board of the National Academy of Sciences, is of more than passing interest to the Naval scientific community. In each of the general fields of investigation for which the Academy has recommended stepped-up activity, the Navy has been a major pioneering force. This fact is pointed out in numerous articles which have appeared in NAVAL RESEARCH REVIEWS *in the past. The work of the Naval Research Laboratory in radar and radio astronomy and x- and gamma-ray astronomy, the investigations conducted for the Office of Naval Research at observatories throughout the land, and the perfection by ONR of instruments and balloons capable of making a variety of observations above most of the earth's atmosphere are but a few examples of Navy efforts to gain "footholds" of understanding on the frontiers of astronomy.*

To indicate where these past and current achievements may lead, the following review of the Academy report is presented.

Two immense orbiting telescopes that will be comparable to the largest ground-based astronomical facilities have been proposed as ultimate objectives of the national program in space astronomy during the next 20 years. Recommendations for initial studies of the two instruments—a 120-inch or larger optical telescope and a radio telescope having an aperture of approximately 12 miles when extended—are contained in the second report in the series, "Space Research: Directions for the Future," issued on February 1 by the Space Science Board of the National Academy of Sciences.

The report describes in detail both immediate and long-term scientific and instrumental objectives for space astronomy, building on the present capabilities for making rocket and balloon observations above the atmosphere and for launching unmanned Orbiting Astronomical Observatories and Orbiting Solar Observatories.

According to the report, the projected space telescopes hold the potential for making decisive contributions to the understanding of many central scientific problems in astronomy, including, for example, the optical resolution—not possible with existing telescopes on the ground—of quasi-stellar galactic nuclei, in which the vast energies of these distant sources are thought to originate.

While laying a basis for orderly progression toward orbiting observatories of increasing power and stressing the unique capacities of these instruments to extend man's view of the universe, the report emphasizes that efficient use of such costly and complex facilities in space will continue to require the most complete astronomical data obtainable by means of ground-based observations.

To this end, it is urged that support be given to meeting a number of objectives in addition to that of launching orbiting observatories. They are as follows:

- More rapid growth of ground-based astronomy along the lines of the 10-year projection of needs for large optical and radio telescopes contained in a 1964 report by the Academy.
- Development of specialized instrumentation for ground-based solar astronomy in addition to the development of the universal instruments described in the 1964 report.
- A doubling of the launchings of sounding rockets for research in optical, solar, and x-ray and gamma-ray astronomy, and improvements in guidance and flight stability of these vehicles.
- Laboratory studies leading to more efficient detection and recording of radiation in all regions of the electromagnetic spectrum.
- Substantial increases in balloon flights for radar and for x-ray and gamma-ray astronomy and development of systems to carry balloon-borne payloads to altitudes higher than the present limit of from 100,000 to 150,000 feet.

The report suggests that an orbit of 20,000 miles or more above the earth would be preferable to either a low earth orbit or to a location on the moon for the proposed very large optical and radio observatories. Man probably would be needed in space for the assembly and/or initial adjustment and for periodic maintenance and repair of the instruments. The useful scientific life of these major national facilities would be years or decades, compared with the 12-month or shorter lifetimes of smaller, unmanned telescopes now being prepared for launching, the report states.

The concentration of future effort on a single general-purpose instrument—the large optical telescope—is justified, according to the report, because of the more favorable signal-to-noise ratio that might be obtained as compared with that obtainable from many smaller instruments in orbit simultaneously, the relative simplicity of providing for manned servicing of a single telescope rather than a number of telescopes, and the great flexibility that such a general-purpose instrument would afford in planning long-term observational programs.

The engineering conception of the large radio telescopes—which would have a 12-mile lateral dimension—is, necessarily, not as clear-cut as that of its optical counterpart. The report points out that the mechanical problems of launching, unfolding, erecting, and using an antenna of this scale in space can, as yet, be discussed only in general terms. It states, however, that "it seems certain that a structure made basically of wires held in place by some stabilizing system could meet the need and be practical." The possibility of stabilizing the extensive array by means of small vehicles carrying thrusting devices or by gravity-gradient methods is suggested.

Intermediate steps recommended to be taken in anticipation of the development of these instruments are the inclusion in the Apollo Extension Systems program of two or more optical telescopes having apertures of 40 inches or more and the testing in that program of the principles on which the very large radio antenna would be based.

For the more immediate period, the report examines the needs not only in optical, solar, and radio and radar astronomy, but also in x-ray and gamma-ray astronomy, and it identifies special problems in geophysics and physics which will be susceptible to attack with the advent of the Saturn series of rockets capable of placing very large payloads in orbit.

"The fact that none of the celestial phenomena known previously had led astrophysicists to predict the existence of x-ray sources even remotely approaching the strength of those observed justifies the expectation that x-ray astronomy will play a fundamental role in advancing our understanding of the universe. . . Every ingredient exists in the young field of x-ray astronomy to guarantee its development in a manner that may soon lead to results comparable in importance to those of radio astronomy."

The future of gamma-ray astronomy, although less certain because as yet no cosmic sources of this radiation have been detected with certainty, is no less exciting in its prospects, the report points out. For example, our current theories of nucleogenesis indicate that there should be substantial amounts of gamma-line emission from the decay of radioactive elements, even in a supernova remnant as old as the Crab Nebula. Accordingly, the report states that "The fundamental knowledge to be gained from studies of gamma-ray processes is so important that every effort must be directed toward achieving the necessary levels of detection sensitivity." Generally, for x- and gamma-ray astronomy, the report recommends the fullest possible utilization of available vehicles, such as balloons, rockets, and satellites.

Finally, a number of studies of fundamental physical significance are proposed. These studies are made possible by the unique conditions of the space environment—low pressure and temperature, weak magnetic field, and zero-gravity field. The most important of the studies would deal with relativity and gravitation (the gravitational deflection of light), physical constants (the gravitational constant and the velocity of light), and behavior of plasma, the highly ionized "fourth state" of matter.

Chairmen of the working groups responsible for the recommendations in the report were Lyman Spitzer, Princeton University (optical astronomy); Leo Goldberg, Harvard University (solar astronomy); J. W. Findlay, National Radio Astronomy Observatory (radio and radar astronomy); Herbert Friedman, Naval Research Laboratory (x-ray and gamma-ray astronomy); N. U. Mayall, Kitt Peak National Observatory (over-all coordinator for astronomy); and George P. Woollard, University of Hawaii (physical sciences).

The Nuclear NOMAD

A nuclear-powered model of the NOMAD weather buoy, developed by the National Bureau of Standards for the Bureau of Naval Weapons, is now broadcasting weather information at regular intervals from the Gulf of Mexico to monitoring stations ashore. While operating completely unattended, the floating station transmits both general weather data and advanced warnings of hurricanes.

The original NOMAD (Navy Oceanographic Meteorological Automatic Device) was developed in 1955. A series of modifications of the device, made since that time, led to the development of the model now operating in the Gulf, which is powered by batteries kept charged by a SNAP-7D nuclear generator. This generator was developed by Martin Marietta Corporation for the Atomic Energy Commission for long-term, unattended applications.

The NOMAD anchored in the Gulf of Mexico will soon be joined by additional NOMADs placed out of Norfolk, Virginia, and San Diego, California. Each station will broadcast the following weather data by means of the continental code: station identification, water temperature, air temperature, barometric pressure, wind speed, wind direction, and integrated wind force. Each transmission takes about 2-1/3 minutes and can be programmed to occur at intervals of 1, 3, 6, or 12 hours. These transmissions should aid in predicting the arrival of storms early enough for ships and planes to change their courses and for populated areas to make preparations.

The 1955 NOMAD consisted of a 10 × 20-foot nonmagnetic float that was designed by the Navy's David Taylor Model Basin. It contained circuitry powered by dry batteries. The present model looks much like the first one but contains improved circuitry and a nuclear power source. Many of its sensors, however, are similar to those of previous models. Temperatures of the air and water surface are measured by thermistors having a high negative temperature coefficient. Barometric pressure is converted to a resistance value by clamping the conductive pointer of an aneroid barometer to a circular resistance strip at the moment of sensing. Similar methods are used to sense wind speed and direction; the former is obtained by a tachometer driven by a three-cup anemometer, and the latter is presented in terms of the position of a magnetic pointer. IWF (the amount of time that the wind speed has exceeded a threshold value) is obtained from a multiturn potentiometer that is positioned by a d-c chronometric motor which is controlled by a pressure-plate anemometer.

The resistance values supplied by these transducers are switched in a fixed sequence into a self-balancing bridge. When balanced, the bridge controls a selector and code generator that expresses transducer resist-

The nuclear NOMAD is anchored in the Gulf of Mexico. Weather-sensing devices that are visible include the anemometer, wind-direction indicator, and IWF storm sensor. The radio circuitry, batteries, and nuclear power source are inside wells below the hinged covers on the deck.

ance in terms of the continental code. The generator keys a pulse-modulated transmitter whose signal can be received reliably over a distance of about 800 miles and has been reported to have been received over a path of more than 1600 miles.

The electrical power that operates the telemetry circuitry and navigational lights of the new NOMAD is supplied by three series-connected, 4-volt nickel-cadmium batteries which are kept charged by the 50-watt SNAP-7D nuclear generator. The SNAP-7D, which is mounted below the deck, is a thermoelectric generator that operates by heat from the nuclear source.

Each of the other NOMADs in use obtains its power from 12-volt, lead-acid batteries that provide a capacity of 4000 ampere-hours. Two wind-chargers mounted atop masts charge these batteries sufficiently for station operation over a practical length of time.

During the years in which successive models of NOMAD have been anchored, several different configurations of ground tackle for mooring the float against the stresses of gusts and hurricanes have been tested. The NOMAD in the Gulf is anchored in a depth of about two miles by means of a mooring bridle, from which about 1000 feet of stainless-steel-wire rope descends to about 7500 feet of nylon line, which in turn leads to another 7500 feet of polypropylene line. The polypropylene line is attached to an iron chain, a 1250-pound ballast ball, and a one-ton mushroom anchor. All fittings in the system above the iron chain are of stainless steel.

Research Notes

Polymer Research Sponsorship Rewarded

For 15 years, the Office of Naval Research has provided the incentive, support, and continuous recognition of excellence in the making in polymer science at the University of Massachusetts. Upon this groundwork, the University now is planning a major expansion of its program for this science as a part of a larger interdisciplinary venture in materials. Overall, a $20 million facilities expansion is projected, including a $9 million chemical complex having a 16-story tower, part of which will house the expanded polymer science institute. At least three new professorial chairs are to be added.

Two important meetings have been held to guide the organization of the new polymer enterprise. Early in January, an advisory board met to review the organizational picture and long-range goals and to present a comprehensive picture of work now in progress. Late in February, a conference was held which brought together prominent industrial and academic scientists, about 70 in all, to identify current educational requirements and to obtain the benefits of the most advanced thinking to shape the organization, policy, and program of the enlarged institute.

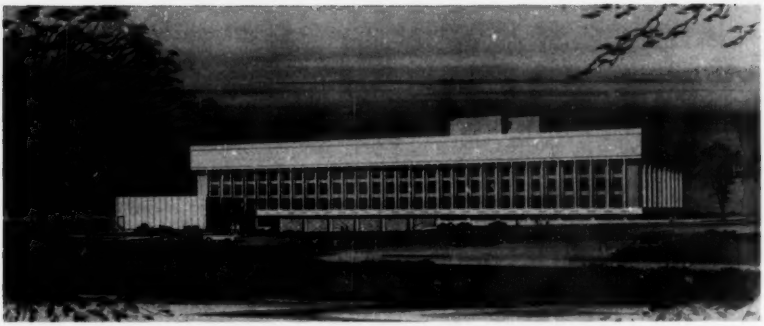
The Ground is Broken Twice

On December 14, ground was broken for two new buildings at the Naval Research Laboratory—a $5 million structure that will house the Laboratory's Atmosphere and Astrophysics Division and a $3 million Operations and Technical Services Building. The new construction, which is scheduled for completion in 1967, is being undertaken as part of a long-range development plan for the Laboratory.

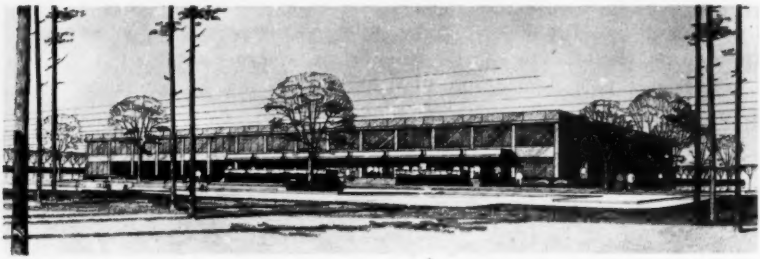
The Atmosphere and Astrophysics Division's new four-story building will house 140 scientists, engineers, technicians, and administrators whose research is directed to the understanding of atmospheric and space processes. Among the tools required for their work are radio and optical telescopes, rockets, satellites, balloons, aircraft, drones, and floating automatic weather stations. The superintendent of the Division is Dr. Herbert Friedman.

Included as part of the A&A Division is the E. O. Hulburt Center for Space Research, which provides an important link between university and government scientists engaged in rocket and satellite astronomy. The Center was established in 1963 under joint sponsorship of the Office of Naval Research and the National Science Foundation. Each year, between six and twelve university faculty members and their Ph. D. candidates work with the permanent NRL staff to further our knowledge of space phenomena. Dr. Friedman is the Center's Chief Scientist.

The Space Center is named after Dr. E. O. Hulburt, who retired from the position of Director of Research in 1955, after devoting almost his entire scientific career to the Naval Research Laboratory. Dr. Hulburt, who is one of the world's most distinguished scientists in the fields of geophysics and the



Artists' conceptions of the General Purpose Laboratory Building (above) and the Operations and Technical Services Building (below).



optics of the sea and the atmosphere, came back to NRL on December 14 to turn over the first shovelful of earth that signalled the beginning of construction of the new building.

The new Operations and Technical Services Building will house some of the administrative and service functions that provide support for the 1100 scientists and engineers actively engaged in research at the Laboratory. These functions include printing, graphic rendition, technical editing and writing, purchase and supply, certain personnel operations, security, budget control, and data processing. The work of NRL's strong support-services staff frees the research staff of support considerations, thus enabling the scientists to devote all of their talents to their investigations.

Mr. Martin E. Jansson, the Technical Information Officer at NRL since 1946, performed the symbolic act of digging the first earth for the excavation upon which the new building will stand.

DSSP now Administered by Office of Naval Material

The Navy's Deep Submergence Systems Project (DSSP), which has been under the Special Projects Office for the past two years, became a separate activity under the Chief of Naval Material on February 1. Objectives of the project have been the development of methods for locating disabled submarines

and effecting the escape and rescue of survivors; the development of means for recovering other objects, large and small, from great depths; and the conduct of the Man-in-the-Sea effort on the continental shelf and in the deep ocean. Highly significant steps toward adapting man to life deep in the ocean for long periods of time were taken last summer during the SeaLab II operation, which was conducted off the coast of southern California by the Office of Naval Research in collaboration with the Special Projects Office.

Equator Expedition 1966

Oceanographers of the Navy Electronics Laboratory departed in mid-January aboard the research ship USS MARYSVILLE (EPCER-857) on a 13,000-mile, three-months voyage into the eastern central Pacific Ocean. The voyage, called Equator Expedition 1966, is concerned primarily with the thermal structure and water currents near the equator. It is the first detailed study of thermal structure to be made so far south (the most southerly point at which investigations were planned is eight degrees south latitude, which is near Guayaquil, Ecuador).

The expedition was undertaken as one of a series planned to study different parts of the Pacific Ocean by means of NEL's unique thermistor chain—an 18-ton, 900-foot-long string of temperature sensors which is suspended from the stern of the MARYSVILLE. On previous expeditions, investigations were made in the northeastern Pacific, Gulf of Alaska, Bering Sea, Gulf of Lower California, and in the vicinity of the Hawaiian Islands.

Objectives of the voyage included studies of the following ocean systems:

- The thermal front off the tip of Baja California. Such zones as this one, in which cold and warm water come together, are important to the Navy because they affect subsurface navigation and acoustic detection.
- Internal waves related to the Cromwell, or Equatorial, Undercurrent. A theory to the effect that internal waves travel away from the equator in both hemispheres was to be tested by means of the thermistor chain.
- The Equatorial Undercurrent. This current, which flows below and in a direction opposite to that of the surface current, appears to terminate or veer to the north or south near the Galapagos Islands. Its speed and direction will be studied by means of current meters deployed along the thermistor chain.
- Boundaries of the Humboldt-Peru Current, which moves northward off the coast of South America then turns eastward to form the South Equatorial Current. The eastern edge of this water body forms the Ecuador-Humboldt front, along which abrupt changes in water properties occur.
- The Gulf of Panama Front and the Gulf of Tehuantepec Gyrals. The Gyrals, which are located off the coast of southern Mexico, are two oppositely rotating water systems that are separated by a thermal gradient.

Only Women could have Broken this Precedent

A 135-year precedent was broken in January, when two lady oceanographers spent about three weeks aboard the Naval Oceanographic Office's research ship USNS LYNCH (AGOR-7) conducting investigations with a crew that on all previous Oceanographic Office cruises had been composed entirely of men.

Mrs. Charles E. Middleton and Miss Joyce Pascoe worked with other scientists aboard the ship obtaining data on water temperature and salinity, velocity of sound in sea water, ocean depth, and other physical characteristics of the oceans as part of a long-range sonar project. The work was done in the North Atlantic.

The senior scientist for the cruise was Frank X. McDougal of the Oceanographic Office. In addition to Mr. McDougal and the two women, the research party consisted of three scientists and three electronic technicians.

The 209-foot LYNCH is the fifth of the AGOR-class ships to be put into operation. The ship, which is manned by the Military Sea Transportation Service, has accommodations for 24 officers and crewmen and 15 scientists.

Flaws in the Law of the Sea

National and international laws governing the exploration and use of the world's continental shelves and other offshore areas will be studied intensively at a conference to be held at the University of Rhode Island next summer. Groups interested in such offshore activities as fishing, mining, conservation, and scientific research will meet with U.S. government lawyers, administrators, and policy makers in an effort to define the rights to which nations are entitled in these areas. The conference will be conducted by the Law of the Sea Institute under the sponsorship of the Office of Naval Research, the Coast and Geodetic Survey, and the Bureau of Commercial Fisheries.

Although two international conferences on the law of the sea have been held in recent years—in 1958 and 1960 in Geneva—the laws regulating the use of offshore sea areas still are not explicit; until they are, the exploitation of marine resources will be impeded. Large-scale investments in the recovery of minerals from the ocean bottom are unattractive to many commercial firms, for example, because of the uncertainty which exists with respect to the legal rights to such exploitation.

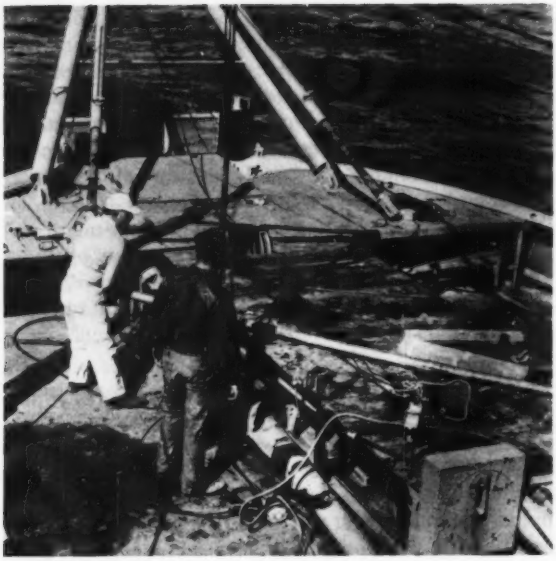
At the present time, the Law of the Sea Institute has projected a three-year program for federal support of study conferences. These conferences will be devoted to the following subjects: Offshore boundaries and zones (1966), extra-territorial fishing rights (1967), and the exploitation of minerals in and beneath the sea floor (1968).

North Pacific Cruise

The 213-foot research ship ARGO, largest vessel in the Scripps Institution of Oceanography's fleet, departed San Diego early in January on a 13,000-mile, eight-month voyage into the North Pacific Ocean.

On the first leg of the cruise, ARGO traveled about 2200 miles due west of San Diego and then about 2000 miles north to Kodiak, Alaska. Over this track, research centered on the biological and physical-chemical structure of the boundary area of the sub-Arctic central water masses.

—Continued on page 36.



Three leaders of North Pacific Expedition are shown at work during previous voyages.

Claude E. ZoBell, professor of microbiology, readies a 30-foot corer for lowering from the fantail of a research ship. He will be in charge of leg 4 of the North Pacific voyage.

Victor Vacquier, professor of geophysics, examines rock samples collected from the floor of the Pacific. He will guide the scientific effort during leg 3 of the expedition.

George G. Shore, Jr., research geophysicist, adjusts a seismic reflection profile recorder. He will lead the scientific party during leg 6 of the cruise.

—*Continued from page 34.*

The second portion of the voyage was to be made along a zig-zag course between Kodiak and Hakodate, Japan. Its purpose, in part, was to observe winter conditions in the ocean area southeast of the Kuril Islands and Kamchatka—conditions about which very little is known. Research was to center also on the exchange of heat between ocean and atmosphere and the nature of the vertical mixing in the water column under extreme weather conditions.

On the third leg of the expedition (Hakodate to Tokyo) geophysical investigations were to be made in coordination with Japanese scientists, six of whom were to be aboard the ARGO. Bahymetry, total magnetic intensity, gravity, and heat flow were to be studied. Later, the geophysical properties of the margin of the Western Pacific will be compared with those of the Eastern Pacific, about which more information is available.

The main objective of the fourth leg of the expedition is to collect and examine deep-sea sediment samples so as to learn more about the occurrence, characteristics, and biochemical activities of bacteria at great depths. Mud cores will be taken from depths greater than 34,000 feet in the Japanese Trench.

The next segment of the cruise, from Tokyo to Honolulu, will be devoted primarily to the measurement of magnetism and gravity and to making several deep hydrographic casts. Work in the Honolulu area will be done jointly with the Scripps research vessel HORIZON and the research vessel TERITU of the University of Hawaii as part of a more extensive investigation of the Hawaiian Arch that is being made in preparation for the Mohole drilling.

On the final leg of the voyage, from Honolulu to San Diego, measurements will be taken of magnetism, gravity, and heat flow. Deep hydrographic casts will be made also.

Arthur S. Fleming Award

Dr. Robert J. Lundegard, head of the Logistics and Mathematical Statistics Branch of the Office of Naval Research, was one of ten winners of the 18th annual Arthur S. Flemming Award, which honors outstanding young men in the Federal Service. The Award was presented in February by the District of Columbia Junior Chamber of Commerce.

Dr. Lundegard was selected for the Award on the basis of his development of the "Standard Maintenance and Material Management System," abbreviated "3M," which is a time-phased plan of action for the installation of maintenance and material management procedures and related data-collection procedures throughout the operating forces. "3M" is designed to provide the information and statistics that are needed for the efficient management of the Navy's maintenance and material resources. It has led to considerable cost savings.

Navy Forecasting Group

The Navy has established a Technological Forecasting Group at the Naval Research Laboratory in Washington, D.C. The action followed the issuance of a

report by the Ad Hoc Navy Technological Forecasting Group that revealed the extent of technological forecasting in all the military services, the fragmented effort within the Navy, and the benefits that could be derived from instituting and implementing a formal technological forecast for the Navy.

The Navy Technological Forecasting Group was activated for a six-month period, commencing November 1, 1965, under the Exploratory Development Division, Chief of Naval Material. It consists of representatives from several in-house laboratories. The objective of the Group is to develop a plan, including methodology and format, for making a technological forecast for the Navy. A technological forecast, incidentally, is defined as "....the prediction of the invention, characteristics, dimensions, or performance and the measure of the confidence level for the occurrence of a technical achievement in a given time frame for a specified level of support."

The forecast will consist of three parts, each addressed to a specific segment of the Navy's scientific or military community.

Part I. Research (Scientific Opportunities). This section will cover basic research knowledge and predictions in the various fields, such as chemistry, physics, mathematics, biology, and the earth and human sciences. It will be addressed to both the research activities and the exploratory development task leaders and managers.

Part II. Exploratory Development (Technical Capabilities). This section will cover the exploratory development areas, including the general categories normally considered by the Navy, and should utilize progress predicted by Part I. It will be addressed to both the exploratory development task leaders and managers and the systems analysts. It will be presented in the form of cost-effectiveness curves, comparative technical capabilities at various levels of support, and subsystem concepts.

Part III. Technically Feasible Systems. This section will cover technically feasible systems that may be anticipated from the technology predicted in Parts I and II. It will be addressed primarily to systems analysts and Naval Operations decision makers. It will be presented in a graphical and descriptive form that indicates, where possible, future performance in terms of trade-off curves, parameter sensitivity curves, estimated measures of effectiveness, and confidence levels of predicted trends.

A plan of attack and milestones to be reached were outlined soon after the Group was activated. In preparing the forecast, the Group will consult with and receive advice and council from an advisory panel of laboratory technical directors and bureau and other command representatives. In May the Group is expected to come up with detailed plans as to how technological forecasting will be accomplished by the Navy.

Evaluation of Basic Research for Administrative Control

• *ACR-111. "Evaluation of Basic Research for Administrative Control," by Richard H. Wilcox. 1965. 26 pp.*

A government agency, such as the Office of Naval Research, which funds basic research through contracts or grants, must make many decisions which affect

—Continued on back cover (inside).

Inventions

Whatever the Conditions, Their Shoes will be the Best

Navy research and development has among its objects the solution of "down to earth" problems as well as the opening of broad new fields of knowledge. One of these problems has been the testing of military shoe-sole leather. It was solved by Patent No. 3,216,238, called "The Military Leather Tester," which was issued to Milton Bailey of the Naval Supply Research and Development Facility, Bayonne, New Jersey. This device, which discloses shoe-leather wearing properties under an array of different definite or prescribed conditions, has initiated what is being called a bold new approach to the traditional technology of sole leather.

In the past, the sole leather of military footwear has been evaluated for the most part on the basis of color, weight, thickness, and process values. But very few of these characteristics could be related readily to performance in the many diverse environments in which Naval personnel live and work. On the basis of tests made with the Universal Leather Tester, investigators have shown that it is possible to specify and evaluate reliably the potential performance of soles in a matter of several hours—an evaluation which previously required wear tests of considerable numbers of shoes and a year or more to analyze the results.

The Universal Leather Tester showed that the Navy's Butyl impregnation process, now applied to all leather outsoles on Department of Defense military shoes, would last 35 percent longer than standard soles when worn on wet terrain, 26 percent longer when worn on dry terrain, and would protect feet against wetting more than three times longer than untreated leathers. The instrumentation, including the commercial control equipment, and the treated test soles provided by all the major American tanners cost only $1000—considerably less than the money required to administer a modest wear test among personnel in a minimum sampling of Navy sites.

The multiparametric approach provided by the Universal Leather Tester has excited the interest of foreign investigators and other parties outside of the field of leather. It has been used also to test rubber and the water resistance of coated materials. Furthermore, the method has been coordinated with the Army and is being standardized currently for use by the Joint American Leather Chemists Association's American Society for Testing Materials Leather Committee.

After the instrument has been standardized and used for specification requirements, it is believed that its measurements of functional properties of sole leather will encourage the development of superior leathers and more economical leather processing.

Removing Hydra's Jacket

One of the problems associated with launching rockets from the ocean—a concept called "Hydra" (see *Naval Research Reviews,* November 1963)—is the removal, at the time of launch, of the flotation gear that keeps the rocket afloat. Generally, flotation jackets are placed at both the forward and aft positions on

the missle so that it can be towed in a horizontal attitude to the launching site and so that it can be kept in a vertical attitude immediately prior to "lift-off."

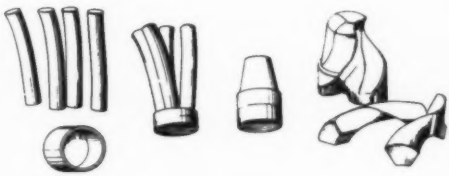
The two flotation jackets differ one from another primarily in the manner in which they are separated from the rocket at the time of firing. Separation of the aft jacket is accomplished by explosive bolts or by the force of the rocket exhaust blast. Since this jacket does not lie directly in the path of the missile, its separation does not present a special problem. The forward flotation jacket, on the other hand, does lie in the path of the missile and must be separated completely at the instant the engines are fired so as not to affect adversely the launching operation. If complete separation is not achieved, an erratic and possibly abortive flight could result.

To assure that the rocket motor will not fire unless complete separation occurs, two employees of the Naval Missile Center—Salvatore J. Penza and Alfred B. Carpenter—invented "A Forward Flotation Means for a Water-Launchable Rocket." According to the invention, foamed plastic or other flotation material is clamped to the forward end of the missile by rings that serve also to hold open the switches in the firing circuit. The rings are fastened with explosive bolts. When the missile is to be fired, a circuit is energized that actuates the explosive bolts. Only if all of the ring clamps are parted will the switches which they hold open be permitted to close and thus initiate firing. If any clamping ring fails to part, the firing sequence cannot progress.

The patent on the concept, No. 3,208,346, was issued to the inventors on September 28, 1965.

The Strip Bullet

A novel bullet that disperses like the pellets of a shotgun shell when fired from rifled arms has been invented by two employees of the Naval Ordnance Test Station. The bullet can be fired interchangeably with ball ammunition without affecting the accuracy of the shot or requiring rifle barrel cleaning or changing.



Views of the strip bullet before and after forming and of the particle fragments after impact. The number of wires included in the bullet can range from two to many.

The invention, called "Strip Bullet," is described in U.S. Patent No. 3,208,386, which was issued to Ottow W. Schneider and Hubert M. Ross, Jr., on September 28, 1965. The bullet consists of a number of pieces of wire, the lengths of which are determined by the caliber and weight of the bullet to be formed, and of a shallow cup. The bases of the wires are fitted into the cup, and the upper portions are swaged into the shape and appearance of a standard bullet.

When the strip bullet is fired through a rifled barrel, the twist imparted to it by the rifling causes the bullet parts to separate by centrifugal force and to produce a "shotgun" pattern.

On the Naval Research Reserve

SIXTH NAVAL DISTRICT REPORTS

Reservists in the Research Triangle

Naval Reserve Research Company 6-6, Chapel Hill, North Carolina, serves the communities of three great southern universities and the fast-developing Research Triangle. The University of North Carolina, Duke University, and North Carolina State University are the principal institutions of higher learning in the area and in large measure the employers of the members of the company. The unit, whose current membership is 23, is commanded by LT Kenneth L. Penegar, USNR-R, an Assistant Professor of Law at U.N.C. in Chapel Hill.

The training program of the unit draws upon the facilities and personnel of these nearby institutions. Thus, there has been exposure to demonstrations of lasers and masers with illustrations of potential military, medical, and scientific uses by faculty of North Carolina State University's Department of Physics. The program designed for basic instruction of the astronauts at the Morehead Planetarium at U.N.C. has been put on for the company. Applications of the digital computers and cyclotron have been demonstrated in recent months. A member of the medical faculty at U.N.C. who participated in SeaLab I and II has lectured to the group. Experts in international economic and political affairs have also brought their research to our classroom in the Naval R.O.T.C. Armory in Chapel Hill. For example, Professor James Ingram of the Department of Economics at U.N.C. recently told of the problems the United States is experiencing relative to the international balance of payments, drawing on testimony he had given before a committee of the Congress.

The opportunities for keeping abreast of fundamental and applied research in a wide range of fields are expanding every year both with the growth of the educational institutions nearby and with the development of the State-sponsored Research Triangle Park. This is an area of land in the center of the open space between the three towns of Durham, Chapel Hill, and Raleigh that has been made available to research divisions of industries to carry on their research in cooperation with personnel from universities in the area. The Environmental Health Laboratory, the plans for which were announced recently by the U.S. Government, will be the latest major addition to the park in terms of facilities and numbers of skilled personnel involved. Such developments promise to enrich the program of NRRC 6-6 directly and indirectly through individual research carried on by many of the unit's members.

Miami Research Unit Tours Computer Facility

The rapid development of the southeast Florida area as a center of electronic research and production was demonstrated graphically to members of Naval Reserve Research Company 6-10, Miami, during a recent tour of Systems Engineering Laboratories, Inc., Fort Lauderdale, Florida. The group was

The operation of a computer-controlled checkout system is explained to members of NRRC 6-10 by LT J. T. Webb, USNR, left, at Systems Engineering Laboratories, Inc., Fort Lauderdale. Others in the group are, left to right, CDR C. M. Broom, LT H. Rudich, LCDR F. P. Seeley, LT J. A. Jones, LCDR J. F. Halladay, and CDR E. D. Scrogin.

conducted through the plant by one of its members, LT J. T. Webb, USNR, who is employed by SEL.

Headed by CDR E. D. Scrogin, USNR, the members saw many of the latest techniques used in the design and manufacture of digital data systems and digital computers. The five-year-old SEL organization is a supplier to NASA and other scientific and engineering organizations. Systems have been produced for the Naval Research Laboratory, Chesapeake Bay Division, the Polaris test facility at Cape Kennedy, and other facilities.

Miami, which is best known as a tourist mecca because of its ideal climate, provides NRRC 6-10's members with opportunities to visit many outstanding centers engaged in a wide variety of research. The University of Miami is expanding continually its research facilities, and the associated Institute of Marine Science is regarded highly for its work in oceanography and marine biology. In addition to the company's visits to these institutions, field trips of unusual interest have been made to laboratories engaged in research on such subjects as lightning, medical engineering, the development of solid-fuel rocket propellant, and communication with dolphins.

Nuclear Sciences Seminar to be Held at Oak Ridge

The myriad applications of atomic energy for the betterment of life on earth and for the exploration of space will be reviewed in the Sixteenth Nuclear Science Seminar at Oak Ridge, Tennessee. The seminar has been scheduled for November 28-December 9, 1966. It will be sponsored by the Office of Naval Research in conjunction with the U.S. Atomic Energy Commission. Local arrangements will be made by Naval Reserve Research Company 6-3, CDR Peter P. Holz, USNR, commanding officer.

Members of NRRC 6-3, which will conduct the Nuclear Sciences Seminar at Oak Ridge, ride in parade for Armed Forces Day.

In past seminars, much attention has been given to the fundamentals of nuclear science. In view of the many scientific and technological changes that are occurring continually in this broad field, the emphasis for the 1966 seminar is being shifted to reflect some of the specific applications which the Naval Reservist will find both timely and interesting. Some of the topics for presentation are presented briefly below:

- The manufacture of unusual devices for nuclear and space applications has presented technological obstacles that are almost insurmountable. Special techniques developed at the Oak Ridge Y-12 Plant for the fabrication of radiation shields for the Nomad navigation buoy, the SNAP 10A, a blood sampling capsule first used in Gemini 3, and other unusual instruments will provide an insight to solving problems concerning which no previous experience existed.
- In the biological sciences, human knowledge is diverging toward greater horizons; therefore, greater emphasis is planned in this area. The effects of radiation on organisms are being investigated. Ultra-high-speed centrifuges (150,000 rpm) that operate continuously at high capacity are being directed toward the separation of a wide spectrum of particles of biological origin ranging from viruses to cellular components. Research on synergistic effects of various carcinogens, such as viruses, radiation, and certain chemicals are planned for a specially designed facility to be built in Oak Ridge. The mysteries of the energy-conversion steps of photosynthesis are being investigated. A new University of Tennessee graduate school of biomedical sciences is scheduled to open in Oak Ridge in 1966. The Center will contribute significantly to this field in the years ahead.
- Our nuclear task force has joined the fight to check the spread of communism in southeast Asia. A progress report on the effectiveness of this force is planned for military applications day.

• Men of the sea always have been concerned with the problem of obtaining fresh water. Our modern ships of the line require great quantities of fresh water for both personnel and machines. At the Oak Ridge National Laboratory, a study now is being made concerning the desalting of sea water by means of large-scale dual-purpose nuclear reactors that may well offer a panacea for all mankind. A conceptual design for a 250 million gallon per day nuclear-powered desalination plant that would supply the water and power needs for a typical city of 1.5 to 2.0 million population is being developed.

• The accumulation of radioactive wastes continues to present many problems to the nuclear industry. Studies of methods of disposal that are being made at Oak Ridge include the utilization of hydrofractured bedrock and abandoned salt mines as waste depositories.

These programs represent a sampling of areas of interest to be presented. Sponsors of these programs include the Atomic Energy Commission, Oak Ridge National Laboratory, National Institutes of Health, Tennessee Valley Authority, and the University of Tennessee.

Second in the Sixth

Naval Reserve Research Company 6-17 of Huntsville, Alabama, was presented a plaque award on November 17, 1965, for "General Excellence and Performance." The presentation was made by LCDR Ernest Littlejohn, USNR, representing the Commandant of the Sixth Naval District, to LCDR James H. Hoyle, USNR, commanding officer of NRRC 6-17.

The Huntsville company received recognition for placing second among all Research companies within the Sixth Naval District for fiscal year 1965.

LCDR Hoyle, left, is presented the second-place plaque award for "General Excellence and Performance" of NRRC 6-17 by LCDR Littlejohn, right. Looking on is CDR J. D. Jones, Jr., a member of the company.

The unit consists of 30 officers, primarily engineers and scientists, who are engaged in studies relating to missiles and space.

Members of the company, which include two captains who were promoted in 1965, are determined to rise above the second-place position before the year ends.

* * *

Colorado Springs Seminar Draws 120 Officers

Naval Research Reserve Company 9-26 of Colorado Springs, Colorado, under the command of CDR John C. Burt, USNR, hosted a three-day seminar, November 12-14, 1965, for Reserve officers of the Army and Navy. In furtherance of the Naval Research Reserve mission to maintain a cadre of highly trained technical personnel to meet the research mobilization needs of the Navy, the seminar was designed to familiarize the attending officers with the technical aspects and problems of the various military establishments located in the Pikes Peak region.

The seminar opened Friday evening with a dinner at the Ent Air Force Base officers club. The guest speakers were CAPT R. P. Gift, USN, of the Naval Space Surveillance System and CDR O. D. Hughes, USNR, of the Office of Naval Research. Saturday morning, the 120 visiting officers received a briefing on NORAD operations and toured the NORAD Combat Operations Center located at Ent Air Force Base. Saturday afternoon was spent touring and receiving briefings on facilities at the U.S. Air Force Academy. Sunday, the Reservists were given briefings on the mission of Fort Carson, the Navy Space Surveillance System, and the hardened NORAD Combat Operations Center. The officers then proceeded to Cheyenne Mountain to inspect the nearly completed NORAD site. The seminar ended with a trip to Fort Carson for closing ceremonies at the Fort Carson officers club.

Members of NRRC 9-26 greet guest speakers. Left to right are CAPT Charles W. Mathews, USNR, master of ceremonies for the seminar; CAPT Ronald P. Gift, USN; CDR Orval D. Hughes, USNR; CAPT John K. Sterrett, USNR, program chairman for the seminar; and LT John K. Fogg, USNR, seminar publicity officer.

Research Reserve units from as far east as Dayton, Ohio, traveled to Colorado Springs for the seminar. The Navy was also proud to host two Army Research and Development companies from Saginaw, Michigan, and Park Ridge, Illinois. All of the attending officers proclaimed the seminar a complete success.

NRRC 4-1 Annual Inspection

On December 1, 1965, NRRC 4-1, Princeton, New Jersey, was given the fiscal year 1966 annual inspection. The inspecting officer was CDR D. McKinlay, Jr., USNR, Reserve Assistant, Office of Naval Research Branch Office, New York. A former member of the company, RADM H. H. Hess, USNR, was an honored guest for the meeting.

This 29-member company, under the command of CDR E. C. Reichard, USNR, boasts of many junior officers in its membership—14 in the grade of lieutenant or below. At the other end of the rank structure, the company claims three captains who provide experience and policy guidance.

There was Talk of Football and Nuclear Propulsion at the Annual Meeting

Naval Reserve Research Company 3-7, Scotia, New York, held its annual dinner meeting on November 4, 1965, at the officers mess at the Naval Corresponding Course Center, Naval Depot, Scotia. Guests of honor included

Engaging in congratulations and conversion at the annual dinner meeting of NRRC 3-7, are, from left to right, CDR A. H. Markham, former commanding officer, CDR McKinlay, LT Pedersen, Mrs. Ploetz, CAPT Ploetz, and CDR T. J. Gair, USNR, also a former commanding officer of the group.

CDR Donald McKinlay, Jr., USNR, Reserve Assistant, Office of Naval Research Branch Office, New York; and CAPT George L. Ploetz, USNR.

CAPT Ploetz, who is retiring from the Navy this year, was praised recently by "Sports Illustrated's" Silver Anniversary American Football Team for his exceptional success in the 25 years since his senior collegiate football season of 1940. In civilian life, CAPT Ploetz is supervisor of ceramic development at Knolls Atomic Power Laboratory. He is also a former chairman of the central New York section of the American Ceramic Society. The commanding officer of NRRC 3-7, LT Lawrence C. Pedersen, USNR, commended CAPT Ploetz for outstanding service to the country during World War II, during which he served aboard submarines, and for his many significant contributions to the development of nuclear propulsion for submarines.

CDR McKinlay expressed his pleasure in the progress made by NRRC 3-7 since his last visit.

Award Presented to NRRC 8-1

Naval Reserve Research Company 8-1, New Orleans, Louisiana, not only placed first in District competition among nine Research Reserve companies in the Eighth Naval District but also placed first among the 46 Specialist and Composite companies in this Naval District. NRRC 8-1 was honored at ceremonies held at the U.S. Naval and Marine Corps Reserve Training Center, New Orleans, on December 7, 1965. CAPT Troy T. Guillory, USN, Deputy Chief of Staff for Naval Reserve on the staff of RADM Pierre N. Charbonnet, USN, Commandant of the Eighth Naval District, presented the winning plaque to CAPT Ernest P. Johnson, Jr., USNR, commanding officer of NRRC 8-1.

CAPT Guillory, left, presents first-place plaque to CAPT Johnson.

General Excellence Award Presented to San Diego Company

In a letter dated December 14, 1965, the Chief of Naval Research, RADM J. K. Leydon, USN, announced that Naval Reserve Research Company 11-5, San Diego, California, had won the fifth national competition for the General Excellence Award for fiscal year 1965.

The Award was presented to NRRC 11-5 during ceremonies following a banquet held at Commissioned Officers Mess, Marine Corps Recruit Depot, San Diego, on February 1, 1966. The plaque, emblem of the Award, was given to the commanding officer of the company by RADM F. A. Brandley, USN, Commandant, Eleventh Naval District. Honored guests included CAPT F. R. Whitby, USN, CAPT W. R. Harman, USNR, and CAPT E. L. Huie, USNR, all members of the District staff; CAPT J. D. Kuser, USN, Commanding Officer, ONR Branch Office, Pasadena; CAPT D. J. Marker, USNR, Special Assistant, Research Reserve, ONR, Washington; and LCDR T. J. Kennedy, USNR, Research Reserve Assistant, ONR Branch Office, Pasadena.

The winner of the award was selected by a panel of officers representing the Chief of Naval Operations, the Chief of Naval Personnel, and the Chief of Naval Research. Each District Commandant nominated the company deemed outstanding in his District for consideration by the panel. The nine other top competing companies are located in Providence, Rhode Island; Upton, Long Island, New York; Philadelphia, Pennsylvania; Frederick, Maryland; Nashville, Tennessee; New Orleans, Louisiana; Lafayette, Indiana; Monterey, California; and Seattle, Washington.

The commendation for the award cited particularly the 12th annual Research Reserve seminar, "New Research Horizons," which was held in San Diego from October 19 to 30, 1964.

In the announcement of the award, LT Edward H. Anderson, Commanding Officer of NRRC 11-5 during the period covered by the award, and the members of the company were congratulated for the outstanding manner in which they had carried out their program of training. "Winning the award is a real achievement," Admiral Leydon said, "since the company was in competition with others designated as outstanding by each of the Naval Districts in the continental United States."

CAPT Kuser wrote to LT Anderson that the award "reflects the high caliber of officers in your company and the conscientious accomplishments you presented for the year concerned."

West Coast Seminar

"Man's Conquest of the Sea" was the subject of the 13th annual West Coast Research Reserve Seminar, which was held on Treasure Island, San Francisco, California, from January 24 to February 4, 1966. The seminar was sponsored by the ONR Branch Office, San Francisco. Naval Reserve Research Company 12-5, CAPT Richard W. Smith, USNR, commanding, was the host company. Programming assistance was given by other research companies in the San Francisco

Bay area. CDR James A. Bassham, USNR, of NRRC 12-5, was seminar chairman.

RADM John E. Clark, USN, Commandant, Twelfth Naval District, gave the welcoming address. Drawing from his long experience in dealing with technological problems of the Navy, Admiral Clark stressed the importance of undersea technology to the future of the Navy and the future of mankind.

The keynote address was given by CDR M. Scott Carpenter, USN, on the mission of SeaLab II, which was undertaken to further the techniques of saturation diving. A principal purpose of such experiments is to make man a free agent for exploration at continental-shelf depths. The use of helium mixed with oxygen as a breathing gas has overcome narcosis problems at depths reached by the SeaLab II divers, but helium causes some problems in vocal communications. More serious is the need for better communications between divers in the water. Improvement is needed also in gas monitoring equipment, oxygen storage, and decompression systems. The preparations for and operations conducted during SeaLab II were reviewed by CDR Carpenter, who reported that morale and performance of the three crews were excellent.

One of the seminar's principal objectives was to acquaint attending officers with the broad scope of man's present achievements and future plans for scientific exploration and economic and military exploitation of the sea. In viewing the many areas of science and technology of the sea, it was expected that each attendee should be able to identify problems in which his particular scientific discipline or technological training might be applied. The seminar proceeded from basic oceanography, marine biology, and research tools through marine geology and meteorology. Economic exploitation of both mineral and biological resources and aspects of naval technology were followed by discussion of legal and political aspects of exploitation of the continental shelf.

Talks ranged from the "Structure of Sea Water," by Dr. Ralph A. Horne of the Arthur D. Little Company, Cambridge, Massachusetts, to "The Continental Shelf Doctrines," by CDR Harley E. Dilcher, USCG, Legal Officer, Twelfth Coast Guard District, San Francisco.

Making presentations were outstanding scientists and engineers from the University of California at Berkeley, San Francisco, Los Angeles, and San Diego (Scripps Institution of Oceanography), Hopkins Marine Station of Stanford University, the University of Hawaii, California State College at Long Beach, and Oregon State University. Authoritative talks were presented by engineers from industry, including Lockheed Space and Missiles Company, W. A. Bechtel Corporation, Westinghouse Electric Corporation, and Ocean Resources, Incorporated. Eminent speakers came also from several government laboratories and military installations and from public and private research institutions. The California Academy of Sciences was represented by Dr. Robert T. Orr, Associate Director, and by Dr. Earl S. Herald, Superintendent and Curator of Steinhart Aquarium, who is well known for his award-winning television program, "Science in Action." Seminar attendees were privileged to hear LCDR Brad Mooney, USN, one of six qualified U.S. hydronauts.

One of two field trips was to the U.S. Army Corps of Engineers' San Francisco Bay Model in Sausalito. The next stop was the Bureau of Sports Fisheries

GPO : 1966 O—209-666

Laboratory, U.S. Department of Interior, Tiburon. Methods and equipment used in mapping and estimating concentrations of fish of the West Coast were described. The afternoon was spent with the U.S. Bureau of Mines' Minerals Technology Center, Tiburon, viewing equipment being developed for obtaining sea-floor mineral samples. During this tour, the officers went aboard two experimental oceanographic vessels.

The second field trip was to the San Francisco Bay Naval Shipyard, Mare Island Division. Following presentations on the "Navy's Deep Submergence Program" and "Protection of Underwater Structures," the officers toured the machine shops and went aboard the TRIESTE II and the SSN-662 GURNARD—both under construction. The tour concluded with a talk on "Quality Control."

One of the highlights of the seminar was the banquet address by CAPT George L. Street, USN, Commander, Submarine Group, San Francisco Bay Area, a holder of the Congressional Medal of Honor. Officers and their wives present were treated to World War II reminiscences and exciting film clips. CAPT Street, whose many and varied billets have included service as Head of the Subsurface and Surface Warfare Section of the Office of Naval Research, emphasized the value of a close relationship between the Naval scientific community and the Fleet.

Seminar enrollment was 103 Naval Reserve, five Army, and two Air Force Reserve officers.

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the course of that research. Contract renewal or support-level modifications are particularly important, but several other types of action (including lack of action) have important effects. Unfortunately, the unpredictability of basic research and the absence of a profit motive make quantitative evaluation and objective decision-making difficult if not impossible. Furthermore, the interests of the sponsoring agency must be pursued without unduly restricting or hindering the research itself.

To help guide the evaluation of basic research and thus guide decision-making in research administration, the author proposes a mathematical model that combines the primary considerations of quality and appropriateness of research and communication of results; provision is also made for important supplemental considerations. Numerous indicators of these factors and their sources are identified. The report is concerned solely with the evaluation of existing research tasks, not with the selection of new ones for support.

Available from the Clearinghouse for Federal Scientific and Technical Information, U.S. Department of Commerce, Springfield, Virginia 22151. Price, $2.00 per copy. Available to qualified organizations from the Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314. When ordering, refer to publication symbol: AD624143.

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EDITOR: Richard D. Olson NAVSO P-510

Dr. Isabella Karle of the Naval Research Laboratory examines a model of an alkaloid, the structure and molecular formula of which she has determined by x-ray diffraction. The molecule was derived from a substance produced by a tropical plant that is being investigated because of its possible application as a blood-pressure depressant. Mrs. Karle and her husband, Dr. Jerome Karle, also of NRL, are making determinations of this kind on a number of plants for the National Institutes of Health.